We sincerely thank the reviewers for their constructive feedback and valuable suggestions. Below, we provide detailed responses to all comments. Reviewer comments appear in black, while our responses are shown in blue and indented. Text newly added to the revised manuscript is italicised, and the reference to line numbers correspond to the "clean" version of the revised manuscript. References cited in our responses are listed at the end of this document.

Reviewer 1

General comments

Overall, this paper is well written and organized, and provides a valuable contribution for efforts to conserve biodiversity in Australia. More generally, discussing and working through a few aspects described below would strengthen this paper.

> We are grateful for the reviewer's thorough, constructive, and insightful comments. We appreciate the opportunity to clarify, expand, and improve our manuscript accordingly. Below, we provide point-by-point responses to each major and specific comment, explaining the revisions implemented in the text.

This approach is relevant to reporting on the Global Biodiversity Framework, as the authors point out. As a result, the alignment of the "pressures" with the stressor/threat taxonomy (https://www.iucnredlist.org/resources/threat-classification-scheme) should be clarified. This may be a semantic difference between the definition of a "pressure" vs. a stressor/threat – is this considered the same as a stressor/threat in the framework? There are 16 pressures mapped here (and in previous datasets fewer). What is the rationale for including these pressures, and not others? Is it lack of data or relevancy? What happens when additional datasets are discovered or created – are they included within an existing pressure or not? E.g,. why are major roads and minor roads a single pressure, when trails and railroads are distinct from roads (and from each other). Please clarify the relationship of the pressures to the stressors framework.

> We thank the reviewer for this insightful comment. We have now clarified in both the Introduction and Methods section the conceptual alignment between our definition of pressures and the IUCN–CMP Threat and Stress Classification Scheme (Salafsky et al., 2008, 2025). In the Introduction, we also now define pressures as human activities with the potential to harm nature, broadly corresponding to direct threats or stressors in that framework. We also note that cumulative pressure maps have been widely adopted to support pressure–state–response frameworks in environmental reporting and adaptive planning (Watson & Venter, 2019), consistent with the conceptual foundation of the original Human Footprint approach (Sanderson et al. 2002).
>
> The revised text included in the introduction reads as follows (lines 47-51):
>
> "*Here, we use the term "pressure" to denote human activities with the potential to harm nature (Borja et al., 2006; Martins et al., 2012), broadly corresponding to "direct threats" or "stressors" in the IUCN Threat and Stress Classification Scheme (Salafsky et al., 2008, 2025). Such pressure maps are increasingly used as proxies for human influence on ecological state*

and condition, particularly within pressure-state-response frameworks used to guide adaptive planning and management (Watson and Venter, 2019)."

In the Methods section, we further highlight this alignment and refer readers to a new supplementary table (see below) that shows the correspondence between each mapped pressure and its corresponding IUCN–CMP threat class.

The revised methods now read (lines 115-117):

"Each mapped pressure aligns with one or more IUCN-CMP threat classes (Salafsky et al., 2025, see Table S1), ensuring conceptual consistency with global biodiversity reporting frameworks (e.g., GBF). This alignment helps guide the selection of pressures to include, clarifies relationships between them, and informs the choice of appropriate datasets and schemes."

By clarifying this relationship, we address the reviewer's broader questions on the rationale for selecting the 16 mapped pressures and the inclusion of new ones in the future. The IUCN–CMP framework provides a consistent structure for evaluating both data availability and ecological relevance, while allowing additional pressures to be incorporated as suitable spatial datasets become available.

The new Table S1 is here:

Table S1.The 16 pressures used in this study, classified into level 1 and level 2 of the IUCN-CMP Threats Classification framework v4.0. The number in front of the threat levels corresponds to the number assigned to each of these in the framework.

Pressure	IUCN classification- Level 1	IUCN classification- Level 2
Intensive land uses	1 Residential, commercial & recreation areas	1.1. Residential Areas 1.2. Commercial & Industrial Areas 1.3. Recreation & Tourism Areas
	2 Agriculture and Aquaculture	2.3 Terrestrial Animal Farming (Farm areas associated with infrastructure). Ranching, Herding 2.4 Marine and Freshwater Aquaculture (areas associated with infrastructure)
Buildings	1 Residential, commercial & recreation areas	1.1. Residential Areas 1.2. Commercial & Industrial Areas
Croplands	2 Agriculture and Aquaculture	2.1. Annual & Perennial Non-Timber Crops
Pasturelands	Agriculture and Aquaculture	2.3 Terrestrial Animal Farming, Ranching & Herding
Forestry (plantations)	2 Agriculture and Aquaculture	2.2 Wood and Pulp Plantations
Mining/ Quarrying	3 Energy Production & Mining	3.2 Mining and Quarrying
Roads	4 Transportation, Service & Security Corridors	4.1. Roads, Trails & Railroads
	6 Human Intrusion and Disturbance	6.1 Recreational activities

		6.3 Other Human Disturbances
Railways	4 Transportation, Service & Security Corridors	4.1. Roads, Trails & Railroads
Oil Pipelines	4 Transportation, Service & Security Corridors	4.2 Utility & Service lines
Gas Pipelines	4 Transportation, Service & Security Corridors	4.2 Utility & Service lines
Transmission lines	4 Transportation, Service & Security Corridors	4.2 Utility & Service lines
Population density	6 Human Intrusion and Disturbance	6.1 Recreational Activities 6.3 Other Human Disturbances
Hiking Trails	6 Human Intrusion and Disturbance	6.1 Recreational activities 6.3 Other human disturbances
Navigable waterways	6 Human Intrusion and Disturbance	6.1 Recreational activities 6.3 Other human disturbances
Reservoirs/ dams	7 Natural System Management & Modifications	7.2 Dams & Water Management/Use
Farm dams	7 Natural System Management & Modifications	7.2 Dams & Water Management/Use

The arbitrary but explicit scoring of impact strength associated with each pressure is described (e.g., a value of 10 for built-up lands) and addressed briefly in the limitations/caveats section. But, work on mapping human pressures generally, particularly in the context of national (or smaller regional, local applications) as described here, would benefit from a more data-driven approach/method to develop the scores. There are many papers that have used the general scoring scheme that this work builds on, but national-level mapping provides an opportunity to further improve how these scores are estimated or assigned – at least mentioned in the limitations section. In particular, methods from decision science that can elicit expert information in more careful, robust ways. In addition, the mapping approach described here would be strengthened by briefly discussing other work on mapping human pressures – at global and national scales (more specifics below).

We have expanded our review to cover other global and national-scale pressure mapping studies (which aligned with suggestions from Reviewer 3 to provide more context on cumulative pressure mapping advances).

> Lines 46-73 in the introduction section now read: "*The field of cumulative pressure mapping, in which data on multiple pressures are integrated under a spatial model (maps), has become a widely used approach to estimate human pressures on the environment (Watson et al., 2023b). Here, we use the term "pressure" to denote human activities with the potential to harm nature (Borja et al., 2006; Martins et al., 2012), broadly corresponding to "direct*

threats" or "stressors" in the IUCN Threat and Stress Classification Scheme (Salafsky et al., 2008, 2025). Such pressure maps are increasingly used as proxies for human influence on ecological state and condition, particularly within pressure-state-response frameworks used to guide adaptive planning and management (Watson and Venter, 2019). The conceptual foundations of cumulative pressure maps emerged in the 1980s (Lesslie and Taylor, 1983, 1985; McCloskey and Spalding, 1989), but the discipline has expanded rapidly over the past two decades, with advances in Earth observation and geographic information systems (Watson et al., 2023b; Watson and Venter, 2019). The Human Footprint of Sanderson and colleagues (2002) is arguably one of the most influential early global assessments of humanity's influence on the terrestrial planet, and mapped at a 1 km resolution, provided a framework to quantify anthropogenic influence across nine major pressures. This framework has since been refined and adapted to incorporate additional pressures (Kennedy et al., 2019; Venter et al., 2016a), regional contexts (González-Abraham et al., 2015; Hirsh-Pearson et al., 2022; Martinuzzi et al., 2021; Theobald, 2013; Woolmer et al., 2008), and alternative models for aggregating pressures (Halpern et al., 2008; Theobald, 2013), while recent efforts have achieved spatial resolutions of 100–300 m and annual updates (Gassert et al., 2023; Mu et al., 2022; Theobald et al., 2025). Comparable methods have also been applied in marine systems to quantify the extent and intensity of human use of the oceans (Ban et al., 2010; Halpern et al., 2008, 2015; Micheli et al., 2013).

Cumulative pressure maps are understood to represent potential human influence rather than the realised ecological state or condition of natural systems (Theobald et al., 2025; Venter et al., 2016b). Nonetheless, they have become foundational datasets for ecological research, conservation planning, and environmental reporting, where higher pressures correspond to degraded or lower ecological integrity areas, and lower pressures to areas closer to their natural state. For example, these maps have been used to evaluate relationships between human pressures and species extinction risk (Di Marco et al., 2018; Ramírez-Delgado et al., 2022; Torres-Romero et al., 2025), analyse changes in global mammal distributions (Tucker et al., 2021), population level changes in great apes' behaviour and densities (Kühl et al., 2019; Ordaz-Németh et al., 2021), as well as model the spread of infectious diseases (Skinner et al., 2023). Moreover, cumulative pressure maps have been used in major environmental assessments, including the IPBES Global Assessment (Purvis et al., 2019), the Intergovernmental Panel on Climate Change (IPCC) reports (Masson-Delmotte et al., 2018), and the latest Global Biodiversity Outlook (Hirsch et al., 2020), where they have directly informed indicators of human impact and ecosystem condition."

Regarding the scoring scheme, we agree that developing data-driven or formally elicited scoring approaches would be an important next step for cumulative-pressure mapping, particularly at national scales. In our case, we followed the established Human Footprint framework (Sanderson et al., 2002; Venter et al., 2016) to ensure comparability with previous studies, but we also refined several pressure scores through discussions within our team, which includes researchers with extensive experience in Australian ecosystems and land-use mapping (in the same way that was done in Canada, see Hirsh-Pearson et al 2020). We have clarified this in the methods section (lines 133-138), pointing out how it could evolve to more structured decision-science methods in the future:

"We largely followed past human footprint studies to assign pressure scores to ensure comparability with these (Hirsh-Pearson et al., 2022; Sanderson et al., 2002; Venter et al.,

2016b; Woolmer et al., 2008). Several pressure scores were refined through discussions within our author team, which includes researchers with extensive experience in Australian ecosystems and land-use and pressure mapping, to better reflect national conditions and data characteristics. While this approach provided context-specific refinements, future national applications could further strengthen the scoring scheme through structured decision-science methods (e.g., via Delphi methods)."

We also added a sentence to the limitations subsection (lines 600-601), acknowledging that future refinements could employ structured expert-elicitation or data-driven calibration methods to strengthen scoring schemes. The sentence now reads "*Future refinements could employ structured expert elicitation or data-driven calibration to strengthen scoring schemes*."

While human pressure mapping is often used as a surrogate and is clearly a practical approach to provide critical information for informing conservation, it would be valuable to briefly distinguish the difference with ecologic (or habitat) condition, and what the assumptions are and to what situations this applies, e.g., high pressure corresponds to habitat degradation.

We agree that making the distinction between the values in pressure maps versus habitat condition is important to help interpret the HIF and EII maps. We have now made this explicit in the introduction and discussion sections (and the reviewer's comments on clarifying the difference between the HIF and EII also helped). For example, in the introduction section, we added the following sentences (lines 63-66): "*Cumulative pressure maps are understood to represent potential human influence rather than the realised ecological state or condition of natural systems (Theobald et al., 2025; Venter et al., 2016b). Nonetheless, they have become foundational datasets for ecological research, conservation planning, and environmental reporting, where higher pressures correspond to degraded or lower ecological integrity areas, and lower pressures to areas closer to their natural state.*"

Specific Comments

The terms edge effect, intactness, integrity, fragmentation, and connectivity are used throughout, and part of the paper is on mapping intactness – but it is unclear if these are synonymous or are they different aspects? Rectifying with the biogeography and landscape ecology literature would be valuable, in particular, intactness (as mentioned in the paper) brings in the spatial context/configuration, but is also used to describe individual pixels that are lower than a threshold (e.g., 4). How is intactness different from connectivity (or is intactness a certain aspect of connectivity)? are often used interchangeably. Because the indicator used is intactness, then defining and using it consistently would help to clarify the contribution that it brings to pressure mapping would be more apparent and strengthen a central focus of this paper.

We agree with the reviewer that we needed to clarify how we use these related terms throughout the manuscript, especially intactness. We now provide a clear definition of the term 'intactness' early in the introduction, clarifying the structural component that is captured by the intactness metric we use. We also note that 'intactness' in our context is used as a synonym for 'integrity' to avoid confusion with this other term. Finally, we remove any mention of connectivity to ensure consistency with the terminology used by Beyer et al

(2020) and avoid ambiguity. This has been addressed in the 4th paragraph of the introduction (and throughout the document), and the relevant text reads (lines 74-80):

"Pressure maps have been used as surrogates for ecological intactness. However, intactness (often used as a synonym for areas of high integrity) describes the degree to which systems retain their natural composition, structure, and function (Nicholson et al., 2021). Pressure maps may therefore not fully capture intactness, as they do not account for the spatial configuration and habitat-quality context surrounding each pixel (Theobald et al., 2025). To overcome this, Beyer and colleagues (2020) developed a metric to estimate ecological intactness, which integrates relative habitat quality with the degree of fragmentation, using cumulative pressure maps as the base layer. This approach provides a spatially explicit measure of the structural dimension of integrity, complementing cumulative pressure maps that represent direct human influence."

The uncertainty analysis is helpful – but the map in Figure 4 seems to be generated by extrapolating (using IDW) from the validation points. Because the patterns of human land use can be quite abrupt, an assumption of simple distance decay is overly simplistic. Why not simply show the uncertainty for each pixel (perhaps at a reduced resolution such as 1 km).

We thank the reviewer for this valuable comment. While we acknowledge that extrapolating validation points may appear simplistic, we want to emphasize the efficiency and robustness of this approach. To address the uncertainty associated with expert-derived intensity scores (one of the most common critiques of cumulative pressure maps), we conducted a comprehensive sensitivity analysis. Specifically, we randomly adjusted the intensity scores in the validation samples for each of the 16 human pressure inputs by up to ±50%, using a bootstrap resampling technique. To capture a broad range of variability and ensure a representative empirical distribution of uncertainty, we performed 100,000 simulations.

Given the 100 m spatial resolution of our analysis, the resulting raster file contains more than one billion pixels (40,091 × 38,571). Even at lower spatial resolutions, incorporating the uncertainty across the 16 input layers and subsequently computing the cumulative pressure map demands substantial computational resources.

As discussed by Ligmann-Zielinska and Jankowski (2014), interpolation of samples is an efficient approach to mitigate high computational costs. In our study, the sampling design ensured a representative coverage of the Australian territory by applying a stratified sampling approach following Olofsson et al. (Olofsson et al., 2013, 2014). This allowed us to approximate spatial variations in the uncertainty of intensity scores more effectively. Our results also reflect several aspects highlighted by the reviewer in other comments, such as the amplification of biases and inaccuracies due to the overlap of multiple input layers. Notably, our uncertainty map reveals that areas where multiple human pressures converge tend to be more sensitive to variations in intensity scores.

Please clarify what is meant by high or low resolution by specifying quantitatively what you mean (do this consistently throughout the paper).

We thank the reviewer for highlighting this inconsistency in our use of the terms "high" and "low" resolution. These terms were used in reference to both the very-high-resolution satellite imagery used for validation (<1 m) and the 100 m-resolution maps we produced. We have now revised the text to use "high" or "very-high resolution" only when referring to satellite imagery. For all other cases, we specify the exact resolution or refer to datasets as having relatively higher or lower resolution in relation to others.

L67: Please clarify – perhaps there have been no other efforts carried out *in Australia* – but there are other efforts to map human pressures at a national level – please revise, or better, provide a sentence or two in the introduction that identifies some of these and how your approach is similar or different, strengths and weaknesses.

We clarified that the only previous national-scale cumulative pressure map for Australia was developed by Lesslie and colleagues in the 1980s (Lesslie et al., 1988; Lesslie & Taylor, 1983, 1985) and that no comparable national-scale efforts have been undertaken since then. The revised paragraph in the Introduction (Paragraph 5) now explicitly contrasts this with more recent global cumulative pressure maps (e.g., Theobald et al., 2025), noting that although these global products include more pressures than earlier models, they remain constrained by globally consistent datasets that do not map pressures available on a national scale and arguably important in the Australian context, such as unpaved roads, and farm dams. We then explain that national-scale efforts, such as ours, can integrate locally curated, bottom-up datasets that are regularly updated and aligned with official land-use reporting frameworks, thereby improving both spatial accuracy and policy relevance (Martinuzzi et al., 2018; Scott & Rajabifard, 2017). The paragraph now reads (lines 87-99):

"In Australia, Lesslie and colleagues carried out pioneering work in the 1980s to create the first pressure map at a national scale (Lesslie et al., 1988; Lesslie and Taylor, 1983, 1985). However, no similar efforts have been carried out subsequently for the country, making the available national data highly dated. Global efforts have mapped pressures across Australia, but some of these use a limited set of globally available datasets to represent pressures (Gassert et al., 2023; Mu et al., 2022; Sanderson et al., 2002; Williams et al., 2020) and therefore miss nation-specific critical pressures (Hirsh-Pearson et al., 2022). Others, such as Theobald et al. (2020, 2025), incorporate additional pressures and finer spatial resolution, which likely improves their representation of human influence across many landscapes (Arias-Patino et al., 2024). However, these models may remain constrained by the need to use globally consistent datasets, which might fail to represent features such as rural roads, farm dams, and small-scale mining that are sometimes better mapped within national boundaries. National-scale assessments can overcome some of the limitations of global models by integrating detailed, locally curated datasets derived from bottom-up data collection and long-term government monitoring programs (González-Abraham et al., 2015; Hirsh-Pearson et al., 2022; Martinuzzi et al., 2021; Theobald, 2013; Woolmer et al., 2008). Such datasets are subject to national quality standards and aligned with official land-use reporting frameworks, thereby improving policy relevance (Martinuzzi et al., 2021; Scott and Rajabifard, 2017). "

L68-72. There are other global pressure maps that have addressed these pressures (e.g, Theobald et al. 2025), and other national level maps that do meet your criteria.

We agree that we should have provided examples of other global pressure maps that have attempted to address those pressures in the first iteration of our paper. We have now added explicit reference to Theobald et al. (2022, 2025) in paragraph 5 (see text above) and discussed how global cumulative pressure maps have expanded to include additional stressors and finer resolution.

L72-74 While additional pressures may have improved the results discussed in Arias-Patino et al., the logical conclusion of adding more and more pressures does not follow – most spatial science literature describes the opposite occurring, of compounding errors due to uncertainty. Please modify this statement to address this limitation.

We thank the reviewer for this important observation. We have heavily modified the relevant paragraph where this statement was made. However, the relevant sentence to this idea now reads as follows (lines 91-93): "*Others, such as Theobald et al. (2020, 2025), incorporate additional pressures and finer spatial resolution, which likely improves their representation of human influence across many landscapes (Arias-Patino et al., 2024)*."

L92: "... edge effects from habitat fragmentation..." – edge effects are typically thought of as a different ecological process but are not fragmentation per se. This is clear in the landscape and road ecology literature... also see Sisk, Fahrig work as examples.

We agree that edge effects and habitat fragmentation represent distinct but related ecological processes. The text has been revised accordingly to distinguish between these concepts. The revised sentence in the methods section now reads (lines 130-133):
"For pressures 8-16, we also assigned a score to adjacent areas to reflect indirect disturbances, such as edge effects, habitat fragmentation, and more cryptic forms of disturbance, such as potential access for humans or invasive species to areas previously inaccessible."

Cumulative – land use, mining, cropland, pastureland (so 4 of these are non-overlapping... then is the max value not 50???

This comment is closely related to the one that follows, and by addressing both, we have now clarified how mutually exclusive pressures were considered during the addition stage of the mapping. We have therefore rewritten this section of the Methods to better explain how mutually exclusive pressures were treated (see response to the next comment).

However, to address the specific question on the maximum cumulative value, we note that it is not limited to 50. Although only 561 pixels exceed this value (mostly in densely populated urban areas), such cases occur when multiple non-exclusive overlaps occur. For example, a single pixel with pressure scores of 10 (intensive land use) + 10 (buildings) + 10 (population density) + 8 (roads) + 8 (railways) + 3 (pipelines) + 2 (transmission lines) would reach a cumulative score of 56.

L94-96. Please clarify – the statement on how mutually exclusive pressures coexist was difficult to follow. If a pixel has attentive land use, then it can't have mining cropland or pastureland... then why would they take the max value? I think your assumption/rule is that they are mutually exclusive and so to achieve this you found the maximum value of those 4 pressures. Why weren't others considered? It seems no other land uses can occur in the middle of a highway?

We appreciate the reviewer's careful reading. Indeed, the rule was not explained clearly, but the reviewer understood it correctly. We have now clarified in the *Methods* (Section 2.2, *Human pressures and scoring*) the subset of land-use pressures that was treated as mutually exclusive (intensive land uses, mining, cropland, and pasturelands). When two or more of these pressures overlapped, the pixel was assigned the value of the highest-scoring pressure. We have also added that reservoirs and farm dams are mutually exclusive, and paved roads, unpaved roads, and hiking trails are mutually exclusive as well, with the pixel obtaining the value of the highest-scoring pressure.

All other pressures were allowed to overlap because they represent additional, co-occurring disturbances (e.g., roads, pipelines, population density). Linear infrastructure features, such as roads, railways, pipelines, and transmission lines, were not treated as mutually exclusive, as they rarely occupy an entire 100 m × 100 m pixel; rather, they cover narrow corridors that often intersect with other land uses. Although no other land use can physically occur on a highway, other pressures can still occur within the same pixel as a highway, as the feature covers only part of that area.

The revised text (lines 139-147) now reads as follows:

"Following previous human footprint maps, we defined intensive land uses, mining, cropland, and pasturelands as mutually exclusive pressures, as each represents a complete replacement of natural land cover, unlikely to co-occur with the others within the 100 m pixels used for mapping. Moreover, reservoirs and farm dams are also mutually exclusive, as are paved, unpaved roads, and hiking trails. All other pressure overlaps were allowed to overlap, mainly because they represent additional disturbances that can co-occur spatially in the 100 m pixels used in our analyses (e.g., roads, pipelines, or population density).To avoid spatial overlap among incompatible land uses, we applied a hierarchical rule in which overlaps were resolved by retaining the pressure with the highest intensity score (0–10), for example: built environments ≥ mining > cropland > pastureland. This ensured that only one of these mutually exclusive land-use pressures contributed to each pixel's cumulative score, while allowing other co-occurring pressures to be summed cumulatively."

Please clarify the method(s) used to transform polygons and lines to raster cells. If each cell of 100 m is binary – if a road touches a pixel, it is assigned that value, correct? Or does it follow a fractional basis? If the former, then effectively pipelines, roads, etc. have a ~50 m buffer on them. What is the consequence on calculation of the area of impact? What if you downscaled to 30 m pixels, or compared it to 1000 m pixels – would the overall HIF be the same? I don't think so.

We have clarified in the Methods that all polygon and line features were converted to 100 m raster cells using a binary rule: if any portion of a feature intersected a pixel, that pixel was assigned the corresponding pressure value (using gdal_rasterize with the -at flag). As the reviewer noted, this approach effectively produces an approximate 50 m buffer around linear features such as roads, pipelines, and transmission lines, which may slightly overestimate their directly affected area. We now make this assumption explicit so that readers can interpret the results accordingly. Such generalisations are inherent to raster-based analyses, where spatial precision must be balanced with consistency and computational feasibility. We would also like to note that, in natural and semi-natural environments, the ecological influence of these infrastructures (e.g., edge effects, noise, light, or human access) is likely to extend beyond 50 m (Rytwinski & Fahrig, 2015), suggesting that this representation remains ecologically reasonable. The relevant text read as follows (lines 151-152): "*We used a binary rule to rasterise (using gdal_rasterize, with the -at option) polygon and line features to 100 m raster cells, where any pixel intersecting a feature was assigned the corresponding pressure value.*"

We have also added a note in the Limitations and caveats section acknowledging that this rasterisation process introduces some uncertainty, as it does not account for the proportion of each cell actually covered by the feature. We thank the reviewer for prompting this clarification. Lines (581-584): "*We also note that rasterising vector data at 100 m resolution introduces a degree of generalisation, particularly for narrow linear features such as roads and pipelines, which may occupy only a fraction of a pixel. This can slightly overestimate their direct footprint, although we make the assumption that, in most cases, the ecological influence of such infrastructure extends beyond this area*."

Please clarify, or better calculate the median year of each pressure to describe the "currency" of the map you produced using different years represented by the pressures.

We have calculated the median year of mapping for all pixels within the following pressures, for which the primary dataset was CLUMP 23: intensive uses, croplands, and pasturelands (both native and modified). We have updated Table 1 accordingly and noted that the median year of currency for all pressures is 2022. We have also clarified the "currency" of our maps in the introduction section (Lines 101-1-3), which now reads: "*This study aims to produce two complementary national datasets representing cumulative industrial pressures and structural intactness in Australia around 2022 (based on the median year of the input datasets): the Australian Human Industrial Footprint (HIF) and the Ecological Intactness Index (EII)*".

L119-120, Please clarify – I think that CLUMP was provided in a raster form to you – but it originally was created in vector (polygon) format? This is related to the conversion and representation of smaller feature by relatively large pixels.

Please see the reply to the next comment, which is related to this one.

Related, CLUMP is an interesting dataset and a good example of the benefits of going to a national level where there is unique data available… please provide a brief overview of how they develop their polygons and classes – aerial photography? Land ownership/parcel data?

We have now substantially expanded the description of the CLUM dataset in Section 2.2, including text detailing how jurisdictions create the vector data. The relevant text reads as follows (Lines 174-180):

"Although distributed as a 50 m raster, CLUMP 23 is derived from detailed vector datasets produced by each State and Territory government, through a bottom-up mapping process that combines aerial and satellite images, cadastral and tenure information, zoning data, expert input, and field validation. The vector datasets span various dates (2008–2023) and mapping scales (1:5,000 to 1:250,000) (Fig S2 in the Supplement), reflecting differences in land-use intensity and regional update cycles. The national raster was generated by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) in ArcGIS, so that each 50 m cell represents a single dominant land use based on the management objective of the land manager. We resampled this dataset to 100 m resolution using a majority filter."

It is surprising that nightlights information was not used – when it was used in past HIF maps (e.g., Venter et al. 2016). If more pressures (datasets) lead to higher accuracy (as argued earlier) then why not include it? Are there no oil and gas wells that can be readily detected by gas flaring?

Indeed, night-time lights have been used in previous human footprint (e.g., Venter et al. 2016, Williams et al. 2020, Gassert et al. 2023) and human modification maps (e.g., Kennedy et al., 2019; Theobald et al., 2020; Theobald et al., 2025) as proxies for human activity where direct infrastructure data are unavailable. However, for this national-scale application, we chose not to include them because equivalent or higher-quality datasets were available that directly capture the same or related pressures. A similar approach was followed by Arias-Patiño and colleagues (2024) in a recent study. We have revised our explanation of why we did not include nightlights in our analysis at the end of subsection 2.2 to clarify this point (Lines 187-190): *"A notable modification from previous applications of the HIF methodology is the exclusion of nightlight data as a proxy for infrastructure in rural areas or working landscapes like mine sites (Venter et al., 2016b). We opted not to use nightlights because equivalent or higher-quality national datasets already map these features directly (e.g., CLUM 2023, Geoscience Australia's pipelines and building footprint layers). "*

Also, through extensive visual checks across major mining and energy production regions (e.g., the Pilbara, Surat, and Cooper basins), we confirmed that areas of gas flaring and high night-time luminosity correspond closely with features already represented in our mining and energy infrastructure layers. We note, however, that individual oil and gas wells were not explicitly included in our mapping, and we have added this as a caveat in the Discussion section.

L133 - Urban area is not a land use… remove – replace with residential, commercial, industrial, etc.

We have revised the sentence, which now reads (Lines 197-199): *"This category includes pressures from land uses typically linked with infrastructure and human settlements, such as residential, industrial, intensive horticulture and animal production (e.g., glasshouses, piggeries), and the infrastructure supporting services and utilities."*

L182 - Agreed that data on pastureland and livestock grazing are challenging, the Gridded Livestock of the World dataset(s) would be a valuable addition – please consider adding or describe limitations that precluded their incorporation.

We did consider using the Gridded Livestock of the World dataset to adjust our scores for native pasturelands, but we decided against using it due to its coarse resolution and because they do not capture local or seasonal movements. We have added text in subsection 2.2.6 clarifying this. The text reads (Lines 255-259):

"Spatially explicit national data (e.g., from the Australian Bureau of Statistics) are lacking, and livestock distribution in large arid regions are highly variable through time. Global datasets such as the Gridded Livestock of the World (GLW4; FAO, 2022) and Annual Global Gridded Livestock Mapping, 1961–2021 (Du et al., 2025) were not included due to their coarse resolution (5-10 km), their somewhat outdated baseline, and inability to capture local or seasonal livestock movements. We therefore relied on CLUM 23 based to represent grazing pressure, and we acknowledge this limitation in the Discussion"

It would be valuable to understand what are the proportions of the dominant pressure nationally, and perhaps specific to each location?

We have now added a new table detailing the proportion of the Australian terrestrial area covered by each pressure. It is part of Section 3.1, numbered as Table 3. Roads (66%) and Native pastures (47%) are by far the most extensive pressures.

Please discuss the limitations of the assumption a simple, uniform buffer used to represent "access" away from roads, for example. Traveling off-road depends greatly on the adjacent topography and land cover (not to mention land ownership). Please describe how the method used in the paper compares to methods based on travel time, etc., such as:

> We thank the reviewer for this suggestion, which we have incorporated in subsection 2.2.10. We have now clarified in this subsection that the 5 km buffer used to represent road influence captures not only the direct ecological impacts of roads (e.g., mortality, light, and noise) but also the broader effects of human accessibility that roads enable, such as increased disturbance, resource extraction, and the spread of invasive species. We acknowledge that this uniform buffer is a simplification, as off-road accessibility varies with factors such as topography, land cover, tenure, and hydrology. However, this approach allows for consistent national application and comparability with previous global studies (e.g., Venter et al., 2016b). We have also noted that more sophisticated friction-surface and travel-time models (Nelson et al., 2019; Weiss et al., 2020) could complement this approach in future national updates. The relevant text now reads as follows (Lines 307-311):
>
> *"This distance also serves as a proxy for accessibility and is consistent with recent human-footprint mapping efforts (Hirsh-Pearson et al., 2022), while remaining more conservative than early global maps (Venter et al., 2016b; Williams et al., 2020). However, we acknowledge that this is a major simplification, since off-road accessibility varies with topography, land tenure, land cover, and hydrology. Future pressure mapping in Australia could explore the use of friction-surface and travel-time models (Nelson et al., 2019; Weiss et al., 2020)."*

L216 - Please provide more specific guidance on the edge effect of roads – the citation used (Trombulak and Frissel 2000) is a seminal paper (but is 25 years old), more recent reviews (e.g., Rytwinski and Fahrig 2015) would be helpful to briefly summarize. Are there additional, more recent, and more specific to Australia citations to support the parameterization of the distance?

> We have added the suggested reference (Rytwinski and Fahrig (2015) to support the claim of road effects on biodiversity. We have also extended the methods to clarify that our 5 km distance parameter follows Arias-Patiño et al. (2025), and we reference to an Australian study (McCall et al., 2010) reporting ~70 % lower survival of sugar gliders within 5 km of major roads. Unfortunately, to our knowledge, there are no other relevant citations specific to Australia to support the parametrization. We considered multiple alternative options based on informal consultations with experts, but all involved making a large number of assumptions that would add uncertainties, potentially complicating the interpretation of the results. The relevant text reads (Lines 305-309): *"The 5 km maximum distance follows Arias-Patiño et al. (2025), based on observed road impacts on mammals; for instance, in Australia McCall et al. (2010) reported that sugar glider survival was ~70% lower within 5 km of major roads. This distance also serves as a proxy for accessibility and is consistent with recent human-footprint mapping efforts (Hirsh-Pearson et al., 2022), while remaining more conservative than early global maps (Venter et al., 2016b; Williams et al., 2020)."*

L143: – "... assign a score of 10 for any pixel overlapping a building." – to be clear, this is if the building footprint polygon touches any part of a pixel, yes? If this is common to all other pressures, then this should be stated, or if different, then detailed for each pressure. E.g, that is – a building footprint of 100 m2 would translate to a 10000 m2 pixel, correct? (Yes, you assume some modification around the building). Or, is it the centroid of the pixel that must intersect with the polygon?

We have now clarified how polygons and lines were rasterised. We have already addressed this in section 2.1, as part of our response to a previous comment/question. In this case, any pixel intersecting a polygon (building) was assigned a value of 10. This, indeed, assumes some modification around the building, when the building doesn't occupy all the pixel's area. We have clarified this in the respective methods section (2.2.2), the text read as follows (Lines 207-208): "*Here, we assigned a score of 10 to any pixel overlapping a building, which assumes some modification around the building in pixels not fully occupied by its footprint*"

L145: clarify why there are commission errors – these would be errant footprints?

The building layer for Australia is reported to have a ~1% false positive ratio. Through our own visual checks, we observed this trend, with false positives occurring especially in isolated arid regions, where big rocks were mapped as buildings. We have clarified this in the manuscript, and the relevant text now reads (lines 211-216):

"Building data was obtained from Microsoft (2018), which reports a false positive ratio of ~1% in 1000 randomly sampled buildings. We conducted our own visual inspection of 1000 buildings and observed false positives, especially in arid regions, where big rocks were misidentified as buildings. To reduce these errors, we limited our analysis to buildings located within 200 meters of roads or mining areas, as these are typically associated with built structures. We acknowledge that this filtering may produce a slight underestimation of pressures in remote areas where small buildings exist, but roads are unmapped."

L156: Agreed that degradation is associated with proximity (that are accessible) to human populations. But are maps of human populations (typically based on where residences are located, represented largely by building footprints) then constrained to the pixels they touch?

Physically, yes, they are constrained. But, the transportation network that surrounds population centres and buildings in population centres, and access to adjacent areas that they facilitate, are captured in the mapping. This method attempts to keep it purposely simple and not attempt to add more complex assumptions about the behaviour of populations.

How large are large dams? Many of these visually are comparable to the farm dams. What is the specification, typically in terms of area at full or dam height?

We thank the reviewer for taking the time to go over our various input data layers. This comment helped us realise that an error occurred when creating the reservoirs/farm dam database, in which farm dams were incorrectly added to the reservoir data; therefore, many reservoirs and farm dams appeared to be the same size. This has now been corrected, and the new pressure layers clearly show that reservoirs are, on average, larger (~5,000,000 m^2) than farm dams (~1000 m^2). Major dams have a dam height of at least 10 m, but not all reservoirs in the dataset we used have a wall.

To avoid such issues, we have simplified our workflow. Instead of using the CLUMP23 dataset as our base for reservoirs, we are using a polygon from Geoscience Australia (Crossman and Li, 2015), created in 2015 but updated as needed (last update was in February 2025). We revised the validation samples accordingly, without capturing noticeable changes.

L210: farm dams – buffered by 500 m. Aren't the impacts dominated downstream? Also, large dams are presumably polygons – why is their buffers so much lower than farm dams?

We applied a 500 m buffer to farm dams because these features are predominantly established as livestock watering points; approximately 65% of mapped farm dams overlap with grazing areas. The buffer represents a conservative zone of concentrated grazing, trampling, and vegetation degradation that typically occurs around artificial water points, also known as piosphere (Washington-Allen et al., 2004). Empirical studies in Australian rangelands show that cattle spend about 70 % of their time within 3 km of water and 90 % within 4 km (Cowley et al., 2015; Materne et al., 2025), so a 500 m buffer captures the high-pressure core while remaining conservative at the national scale and compatible with our 100 m grid resolution.

Approximately 35 % of farm dams occur in croplands, mainly for irrigation, although mixed cropland–pastureland matrices are common. Many farm dams can overflow during heavy rainfall, affecting adjacent areas, and when clustered, their local hydrological effects can become cumulative, occasionally contributing to flooding during extreme rainfall events (Kazarovsky, 1996; Pisaniello and Tingey-Holyoak, 2017). Such events are becoming increasingly frequent in parts of Australia due to changing climatic conditions. Moreover, irrigated croplands generally exert greater environmental pressures than non-irrigated croplands. Therefore, although local effects can extend beyond the dam footprint, we consider the 500 m buffer a reasonable national-scale representation of their immediate environmental influence.

We have clarified the justification for using a 500 m buffer for farm dams in Subsection 2.2.9. The text (lines 288-295) now reads: *"We assigned a score of 5 to farm dams, which is extended to 500 m from the dam to account for changes to environmental processes. The buffer assumes a conservative distance of concentrated grazing, trampling, and degradation associated with access to water points by livestock which can extend up to 3 km (Cowley et al., 2015; Materne et al., 2025; Washington-Allen et al., 2004); 65% of farm dams overlapped pasturelands. It also assumes potential spillage during intense rainfall which creates tides of water and, in some cases, flooding when multiple dams are present (Kazarovsky, 1996; Pisaniello and Tingey-Holyoak, 2017). We do not consider downstream pressures due to data availability, and because many farm dams are constructed off-stream (Section 2.2.8). We obtained farm dam data from Malerba and colleagues (2021), who compiled it from different State sources"*

Large reservoirs and major dams were buffered by 500m as well, but as the reviewer noted, the score given was lower. This was done as they are primarily used for urban water supply, hydroelectric generation, and irrigation, rather than livestock watering; thus, we made the arbitrary decision not to underscore the indirect pressures. Prior footprint studies mapped only their inundated area, which already captures the dominant industrial pressure signal (land conversion).

Roads and trails are two different pressures, correct? In the discussion in the paper, it would be valuable to have them separated for clarity.

We assume that the reviewer is pointing out to the overview of roads and trails in the methods section, which are in fact treated as different pressures but where described together in the same section. We have now separated these, with roads still in subsection 2.2.10, and trails as a new subsection 2.2.10.

Trails – why 0.9? Why not 1.0 – seems scoring is ordinal 1-10!? Presumably just the pixels that touch the trail line. Also, please describe which data and key/attribute of OSM was used (what classes of roads, etc.) so that this work can be reproduced if needed.

We have clarified in the Methods section that trails were included as an access-related pressure, representing pathways for human disturbance into remote and protected areas. A low score (0.9) was assigned to acknowledge their presence while avoiding overestimation, given the limited completeness and variable accuracy of national trail datasets. This conservative weighting also aligns with in-country wilderness practitioners we consulted, who argue that low-use trails do not necessarily preclude areas from being considered wilderness. The revised text now explicitly explains this rationale and references the data sources used to compile the trails layer. Attributes to map trails are in Supplementary Tables S7 and S8. The relevant text in the methods sections reads (lines 329-333): "We assigned a low direct pressure score of 0.9 to trails to acknowledge their presence while remaining conservative in estimating human pressures in remote areas. This conservative weighting reflects both the variable quality and completeness of trail data across jurisdictions and expert input from wilderness mapping practitioners, who note that limited or infrequently used trails may not substantially compromise wilderness character"

Be consistent with positional accuracy – you've got that in the table, so probably no need to mention it here.

Agreed. We have removed the mention of positional accuracy from the text as it is already provided in the table.

L235: Please correct – transmission lines are included in other human pressure datasets (e.g. Theobald et al. 2025).

We thank the reviewer for the correction. Indeed, transmission lines have been included in other human pressure datasets as well as pipelines. We have revised the text to focus on the rationale for including these pressures in the mapping. We would like to acknowledge that, by the time we first submitted this study, Theobald et al. (2025) had not yet been published.

L243-244. Good point about service roads paralleling transmission and pipelines.

We appreciate the positive comment.

L255. Because this is an open access publication, please provide the validation data (point locations and scoring from visual inspection) in the repo.

Yes, we will add this to the repository.

Please consider noting that if the stratification was based on the output HIF map, then the randomization was in part based on the resulting map and is not strictly independent.

We thank the reviewer for this helpful observation. We agree that because the stratified random sampling was based on HIF value ranges, the validation sample is not strictly independent of the resulting map. However, we will elaborate as others might read this response; this semi-dependent design is a standard and accepted practice in spatial accuracy assessments (Olofsson et al., 2013, 2014), as it ensures adequate representation of all pressure levels, including rare low- and high-pressure classes that occupy small proportions of Australia's land area. The stratification was used only to allocate sample sizes optimally; individual sample locations were then selected completely at random within each stratum. The visual validation itself was conducted using independent, very high-resolution satellite imagery interpreted by an independent assessor. Therefore, the evaluation still provides an objective and unbiased assessment of map accuracy.

We have clarified this in section 2.3.1 (Validation, Lines 360-364): *"Because the stratified random sampling was based on HIF value ranges, the validation sample is not entirely independent of the resulting map. However, this approach ensured that the full gradient of cumulative pressures was represented, particularly in low- and high-pressure areas that occupy small proportions of Australia's land area. Each sample location was selected randomly within strata, and validation relied on independent, very high-resolution satellite imagery, providing an objective assessment of accuracy"*

L269 - normalized to a 0-1 scale – please provide the formula used – Is this max-normalized? Please describe why the highest cumulative value would be the max value used (and why not the theoretical value of 73?).

We have modified the line in section 2.3,1, adding the following sentence (lines 372 – 374): "*Both HIF and validation scores were normalized to a 0-1 scale using the min-max normalization formula. We used the maximum value observed in our map rather than the theoretical maximum, as there is no location where all pressure factors overlap simultaneously, following Venter et al. (2016)*".

L274 – it is not clear why you also report validation using a 20% threshold of being correct – why not just use the continuous value results?

We agree that the use of the 20% threshold needed clarification, which we have done in the revised Methods section. The relevant text (lines 377-381) reads as follows:

"*We also calculated the percentage of validation samples with agreement between the HIF and validation scores, considering the HIF to match the validation score if they were within 20% of each other on the 0-1 scale (Venter et al., 2016b). This ± 20 % tolerance provides a complementary measure of continuous-scale agreement, offering an intuitive indication of how close predicted and observed values are before categorization. It does not replace the categorical accuracy metrics outlined below, but adds context to the RMSE and R^2 results by highlighting overall precision and bias trends*

It seems that section 2.4 is duplicative of 2.3.1 – is there a way to combine these or distinguish them more?

We appreciate this observation and agree that the original sections overlapped. In the revised manuscript, we have merged Sections 2.3.1 and 2.4 into a single section titled "Validation and Accuracy Assessment." The new structure distinguishes between (1) the continuous validation of the HIF scores using RMSE, R^2, and the ±20% tolerance, and (2) the categorical accuracy assessment of the five pressure classes using user's, producer's, and overall accuracy metrics. We also revised the Results section accordingly to align with this structure, emphasizing how the continuous validation assesses quantitative precision, while the categorical assessment evaluates the reliability of the discrete pressure classes for conservation and spatial planning applications.

Please provide the statistical distribution of the cumulative pressure values (histogram or cumulative frequency distribution) to understand their distribution better. This would be helpful context to understand how a central tendency measure like the mean (or median, etc.) portrays the full range of values. Assuming that the distribution is highly skewed with many more low values (this is typical of spatial data generally), is a mean appropriate metric? Please describe, perhaps in the limitations section, the assumptions/interpretation of the addition of the pressures (although there are 4 that are mutually exclusive).

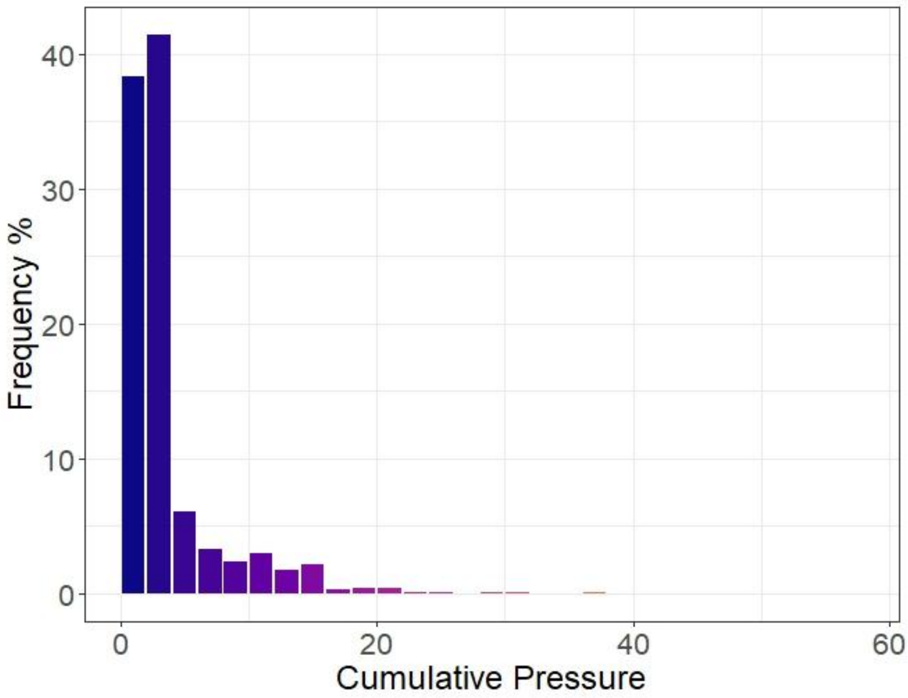
We thank the reviewer for this insightful comment. Indeed, as noted, the distribution of the HIF is highly skewed to the left (see Histogram below). This reflects the spatial patterns of human pressure in Australia, where there are large extents of undisturbed or minimally disturbed lands, particularly in arid lands away from the coast. Based on other comments from the reviewer, we have now merged this subsection presenting overall HIF results with the subsection presenting the results on the classified HIF map. We believe that doing this clarifies the distribution of HIF values in Australia, so we have not added a histogram to the main text. However, we have done so as a supplementary figure (Figure S3). The relevant text (lines 441-451, subsection 3.1) now reads like this:

"The Australian Human Industrial Footprint Index (Fig 2a) map covers an area of 7,692,047 km2 and has a spatial resolution of 100 m. The scores range between 0 (areas with no mapped pressures) and 56.5 (densely populated built-up urban regions), with a mean score of 3.05 ± 4.18, and a median of 2,25. The HIF scores are highly skewed to low values, as seen in the classified map (Fig 3, Fig S3), which shows that more than one-third of the Australian landscape (32%) is free or almost free (score <1) of the 16 pressures included in this analysis, and another 2.9% experiences very low pressures (i.e., scores of <2) (Fig 3). Another 47.5% of the Australian landscape has a low industrial pressure footprint (HIF value ≥ 2 and < 6). These low-pressure areas are primarily pastoral leases that operate without extensive introduction of non-native pastures. However, this analysis does not account for stocking intensity, and we acknowledge that the pressure in some of these areas might be underestimated. Finally, 14.2% of the Australian landscape presents more considerable industrial pressures (scores ≥ 6), with 5.6% of the land being under moderate pressure (scores between 6 and 10) and a further 8.5% experiencing high industrial pressure (scores ≥ 10)."

Regarding the interpretation of the additive pressures, we have added the following paragraph to the Discussion section (lines 555-563):

"The HIF represents a cumulative model of industrial pressures rather than direct ecological conditions. High HIF values indicate areas with greater concentration or intensity of human activities, often associated with degraded states of natural systems; low values indicate areas with fewer detectable or less intense pressures, associated with intact states. As in previous studies, HIF values should be interpreted ordinally, not linearly (Watson et al., 2016; Williams et al., 2020). For example, a pixel with a value of 20 does not imply that it experiences double the pressure compared to a pixel with a value of 10; rather, it can be assumed to be experiencing a higher level of cumulative disturbance. The classified HIF map provides an intuitive framework for communication and comparison across regions,

facilitating policy and planning, and has been used for many diverse conservation applications, including determining species' risk of extinction and the degree of human influence on protected areas (Allan et al., 2022; Jones et al., 2018; Di Marco et al., 2018; Torres-Romero et al., 2025)."



Interesting and helpful validation plot figure 2 (validation). Just curious, why are there horizontal patterns (or even boxes) of points… e.g., mapped values at 0.025.

The pattern observed in the graph mainly results from the fact that some pressure layers have discrete values, for instance, Croplands and Forestry Plantations. Because the y-axis represents the mapped HIF value, the horizontal pattern indicates that the validation plots were located within one of these polygons while also being influenced by indirect pressures, such as proximity to roads.

L312-315. Related to the comment above in the general comments section – intactness includes the spatial configuration. Would be very helpful to clarify this, and not call single pixels as intact or not. This has led to much confusion amongst scientists and policy/decision makers in the CBD Global Biodiversity Framework context.

We agree with the reviewer, and we have defined and clarified the term intactness, and how it is different from habitat quality or "intactness" inferred at the pixel level from cumulative impact maps. This is noted both in the introduction (lines 74-77) and in the methods section (lines xx-xxx). The second paragraph of section 2.4. in the methods section, reads as follows (lines 421-430):

"When pressure maps such as the HIF are used as proxies of ecological condition or intactness, it is done based on thresholds applied to individual pixels with a certain pressure

value (Watson et al., 2016; Williams et al., 2020). However, while the HIF incorporates some indirect pressures that spread out to a buffer from the direct pressure, the value of each pixel does not explicitly account for the spatial configuration and habitat-quality context surrounding that pixel. For example, a narrow strip of native vegetation between agricultural fields could appear to have no pressure because there is no indirect pressure for cropland in the HIF; however, such a strip is impacted by significant edge effects and unmapped human presence, indicating it is somewhat degraded and not intact as the HIF would indicate. Here, we overcome this by calculating an intactness metric (Beyer et al., 2020) for Australia, which is sensitive to changes in habitat area, quality, and fragmentation (and therefore captures the structural component of ecological integrity (Nicholson et al., 2021), which is well known to influence the ability of an area to support a diversity of species (Betts et al., 2017; Fischer and Lindenmayer, 2007; Hanski et al., 2013). "

L330 - remove note on projection – you already described in above and more specifically.

We have removed the note on projection.

The data layers for pressures 7 and 13 were not in the Zenodo repo (forestry plantations, trails). Perhaps these are subsumed in other layers, but should be in separate datasets to maintain consistency.

Thank you for this comment, and we apologize for the confusion. We believe the confusion stems from the numbering of pressures, and we have made the necessary amendments.

L369 – Not tracking these statements – the lower RMSEs could also be a function of resolution – not just increased number of threats, can you disentangle these? This would be valuable to know for sure, but it's not clear that this statement is justified by these initial (but limited) findings.

We agree with the reviewer. The lower RMSEs likely reflect multiple factors, including the mentioned increase in the number of threats, as well as the use of nationally curated datasets mapped at a higher resolution. Anyhow, to avoid overinterpretation of a quantitative RMSE comparison, we have replaced it with a qualitative visual comparison between the national HIF and global Human Footprint products at 1 km and 100 m resolutions (Williams et al., 2020; Gassert et al., 2023). Because these datasets differ in spatial resolution, input data, and pressure composition, a visual assessment provides a more appropriate and transparent basis for evaluating spatial agreement and highlighting improvements in the representation of nationally relevant pressures. The Methods and Results sections have been updated accordingly.

Subsection 2.3.3 in the revised methods now reads as follows (lines 411-415):

"*To assess the added value of the fine-scale national Human Industrial Footprint (HIF), we carried out a visual comparison with global Human Footprint datasets available at 1 km for 2013 (Williams et al., 2020) and at 100 m resolution for 2020 (Gassert et al., 2023). These comparisons were used to qualitatively evaluate how well the HIF captures the spatial patterns of cumulative pressures relative to global assessments. Because the datasets differ in resolution, input data, set of mapped pressures, and some assumptions, interpreting a direct quantitative comparison is of limited value.*

Subsection 3.3 in the Results section now reads (lines 508-516):

"A visual comparison between the national HIF and the global Human Footprint maps at 1 km and 100 m resolutions reveals broadly similar patterns of cumulative pressures across the continent. However, clear mismatches are evident even at a coarse scale. For instance, large parts of inland Australia appear pressure-free in the global maps, yet these areas coincide with native pasturelands captured in the Australian analysis (Fig. 6a). At finer scales, differences become more apparent, arising both from the coarser resolution of the 1 km dataset and from the inclusion of additional nationally curated pressures in the HIF. Examples include Kangaroo Island (Fig. 6b) and the city of Townsville and its surroundings (Fig. 6c), where the national HIF captures unpaved roads, forestry, and pasturelands that are absent in the global products. The Australian HIF also shows finer detail in cumulative pressures within urban centres and peri-urban areas, where features such as farm dams, reservoirs, and unpaved roads are more accurately represented."

L397-402 Remove, this has already been discussed.

The relevant text has been removed.

Perhaps it would be valuable in describing intactness relates to connectivity is to describe – briefly – how EII is similar to a connectivity measure such as Ferrier et al's PARC index or Brennan et al's 2020 circuitscape paper.

Brennan, A., Naidoo, R., Greenstreet, L., Mehrabi, Z., Ramankutty, N. and Kremen, C., 2022. Functional connectivity of the world's protected areas. *Science*, *376*(6597), pp.1101-1104.

We appreciate the suggestion to compare the Ecological Intactness Index (EII) with functional connectivity measures such as the PARC index or Circuitscape-based models, but we believe doing so is beyond the scope of this study. Our analysis follows the framework of Beyer et al. (2020), where intactness represents the *structural* dimension of ecological integrity rather than functional connectivity. To maintain conceptual and methodological consistency with that framework, we have removed separate references to connectivity from the manuscript.

Please align the numbering/naming scheme of the data layers to the description in the text. E.g., human population is 03_ dataset but is 4th in description (2.2.4).

Done

Technical corrections

L58: "Australis" spelling.

Corrected.

L64: "gazettal" – is this a typo or an uncommon word?

We should have written "designation" instead of "gazettal". But under the suggestion of another reviewer, and as an attempt to make the introduction shorter, we have trimmed the paragraph in which we stated all the GBF targets related to intactness or integrity, and this sentence is no longer in the manuscript.

L145: Microsoft (2022) ?? isn't it Microsoft 2018?.

This has been changed to 2018.

L162: WorldPop is at 10 m resolution (or area of 100 m2)? I think you mean 100 m (10000 m2)

The resolution is 100 m (10000 m^2); we have corrected it.

L442: Great to see these limitations, caveats.

Thanks for the positive comment

SI2: is the ABARES dataset the same as CLUMP (in the paper)?

ABARES is the Australian Bureau of Agricultural and Resource Economics and Sciences, creators of the CLUMP 23 dataset. We have modified the column's name to "Land Use code user in CLUMP 23)

Datasets

Built-up - in an ad hoc viewing of the data layer, this data seems this covers a broad range of intensity. Also, consider aligning the file names for the pressures with the description in the text (e.g., 01_builtup = 2.2.1 Intensive land uses. E.g., the town of Lithgow (**150.1527, -33.4815)** and just north near Marrangaroo (**150.11423, -33.44008)** is a much lower intensity area (dominated by forest/shrub). It would be valuable to examine this more systematically to this occurs elsewhere, and address this perhaps by describing the range of land use intensity (perhaps better would be using built-up as a value that ranges from 1 to 10 rather than just 10 or 0, such as is done with human population – but not suggesting that this has to be re-done). Numerous small (5-25 pixels) areas in very rural areas (albeit farmsteads/ranches) occur as well. These seem to be categorically different from high-density residential/commercial in cities. Similarly, there is a fair amount of speckling (single/couple pixels with 0 values) in high density areas e.g., (**151.2506, -33.91478**). This might be related to the conversion of the polygonal CLUMP data to raster (the details of this are needed).

In the revised submission, we ensured that all file names correspond consistently with the pressure names used in the text. The "intensive land use" layer encompasses 47 tertiary CLUMP 2023 classes representing built environments and other highly modified land uses. Given that the class incorporates many different land uses (47 from the CLUMP dataset), future assessments could consider assigning different scores to this range of land use (potentially between 7 and 10, as these are arguably more intense than croplands). However, because most of these land uses represent substantial or complete replacement of natural cover, we retained a uniform score of 10 to maintain consistency with the Human Footprint framework and comparability across pressures. As observed in our uncertainty analysis, modest variation within this range would have minimal influence on the overall cumulative pressure patterns, though future research could refine these scores for urban-ecology applications. We also verified that the observed "speckling" in high-density areas arises from rasterisation of the polygonal CLUMP data and clarified this conversion process in Section 2.2.

Farm ponds and reservoirs

Amazing to see the number of farm ponds! The buffering of the ponds (500 m?) resulting in ~118 pixels seems disproportionate to the un-buffered reservoirs, which presumably have a larger impact in general than farm ponds. For example, at **118.61132, -31.97881** the footprint of the ponds covers ~50% of the land, while many (most?) reservoirs are smaller than a single pixel, and represented by 5 pixels (except for very large reservoirs, eg. >100 pixels. The result seems counter-intuitive, while the intensity value of 8 vs. 5 is higher, the impact is much greater on farms ponds… so 118 x 5=590 vs 5 x 9=40. Please clarify.

We again thank the reviewer for looking at the datasets we submitted, including the individual pressures. Thanks to this and a previous comment, we discovered that some farm dam data was included by error in the reservoir data in the step when these pressures were merged. We believe the reviewer's concern is partially addressed with the correction we have made, as the reservoir and farm-dam datasets are now fully distinct.

Reservoirs are, on average, much larger than farm dams; even after buffering the later, the mean reservoir area remains about 20 times greater. We applied a 500 m buffer to farm dams, as we assume that many of these are established as water points for grazing livestock. The buffer represents a conservative zone of concentrated grazing, trampling, and vegetation degradation radiating from artificial water points (Washington-Allen et al., 2004). For example, studies in Australia's arid lands have shown that cattle spend about 70% of their time within 3km of artificial water points, and 90% of their time within 4km. A 500 m radius thus captures the high-pressure core, while remaining conservative at the national scale and compatible with our 100 m grid resolution. As mentioned in the methods section, a 500m buffer was also applied to the reservoirs, and the confusion might have arisen because of the faulty mapped reservoir layer.

We have now added a short clarifying note in subsection 2.2.9 (farm dams), which reads as follows (lines 289-291): *"The buffer assumes a conservative distance of concentrated grazing, trampling, and degradation associated with access to water points by livestock (Cowley et al., 2015; Materne et al., 2025; Washington-Allen et al., 2004)."*

If two datasets are used to represent the roads, can the same road be represented in both datasets if they don't align spatially, are they double-counted? In a quick look, it didn't appear that there were any, but would be valuable to describe how this was handled. Also, what were the attributes and values used to distinguish major from minor roads and trails?

This is an excellent point made by the reviewer that needs clarification. The situation they described is both a source of potential error, but also a potential source of capturing the real-world nature of roads and road users' actual usage of roads in rural and regional areas. We have now added text, at the end of section 2.2.10 (lines 313-317), that reads as follows: "*Integrating two road datasets introduces the possibility of 'double-counting' when the same road is represented in both datasets, due to the features not spatially aligning exactly within the two datasets; however, because we are rastering linear features at a 100m pixel size, small errors in alignment are most likely removed. Larger spatial alignment errors of the same feature, where found, may be representative of the real-world nature of unsealed roads and tracks in rural and outback areas in Australia, where road users may seasonally take different paths due to high water levels or other factors.*"

Full SQL attribute and data tag queries used for each road type (sealed, unsealed, track, patch) and for each input dataset, can be found in Tables S7 & S8.

Cumulative map

Seems there are counter-intuitive results, e.g., **141.125431, -17.840316** where a major road (National Highway 1) has nearly half the cumulative value (~10.4) than a nearby powerline (18.7). Another example is a series of lower values in the middle of a major road (value of 8, correct) compared to adjacent areas (e.g., **145.69361, -34.08512)** vs. adjacent to the road with a value of 15 (because of other pressures, in this example cropland). Are these caused by the summation of the pressures or something else?

We thank the reviewer for carefully examining the maps. The cases described as counterintuitive indeed arise from the summation of overlapping pressures. For instance, in the first location **(**141.125431, -17.840316), the higher cumulative value (18.7) is the result of the overlap of a railway and a nearby major road (which adds a value of 8 within a 0.3 km buffer), and each contribute independently to the total pressure score. In the second instance (145.69361, –34.08512), areas adjacent to the roads have a higher score, as it converges with pixels representing croplands and a farm dam buffer. We have clarified how the maps can be interpreted, including with the following text in the Discussion section (lines 557-560):

"As in previous studies, HIF values should be interpreted ordinally, not linearly (Watson et al., 2016; Williams et al., 2020). For example, a value of 20 does not imply double the pressure of 10, but rather a higher level of cumulative disturbance."

EII – more detail – even just a sentence or two of how you calculated EII would be valuable. For example, what is the normalization of HIF to 0-1, what was the radius, shape of the kernel used for EII, so that reader doesn't have to go to the Beyer et al. paper for pertinent parameters.

We have now added a brief description of the key parameters used in calculating the Ecological Intactness Index (EII) to ensure the methods are fully transparent without requiring readers to refer to Beyer et al. (2020). Specifically, we clarify that the Human Industrial Footprint (HIF) was normalized to a 0–1 scale and inverted so that higher values represent greater habitat quality. Intactness was then computed within a 5 km circular moving window using the kernel function described by Beyer et al. (2020), which applies a distance-weighted decay with increasing separation among habitat patches. These details have been added to the Methods section (lines 431-438):

"For each 100 m cell, intactness was estimated as a function of the spatial configuration and quality of surrounding habitat, with contributions from neighbouring cells declining with distance. The metric is parameterized to decrease monotonically with increasing fragmentation, reflecting both the number and separation of habitat patches, and to scale with total habitat area and quality. The HIF served as the base layer, normalized to a 0–1 scale and inverted so that higher values represent greater habitat quality (i.e., lower pressure). Intactness values were computed within a circular moving window of 5 km radius using the kernel function described by Beyer et al. (2020), which integrates both patch size and isolation effects. The resulting EII represents the relative degree to which each location retains the spatial configuration and quality characteristic of structurally intact ecosystems.

Reviewer 2

This paper aims to develop the first national-specific human industrial footprint for terrestrial Australia. However, I struggle to understand the rationale behind this work. The production merely summarizes various pressure layers based on subjective scoring, how can the author claim it is 'accurate' or not? Additionally, it lacks practical significance for both biodiversity and ecology, as the article fails to demonstrate this through analysis or discussion. Therefore, I recommend rejecting this paper. Before submitting it elsewhere, the author(s) should reconsider the novelty and practicality of their work and extensively revise the manuscript.

We would like to thank the reviewer for their time and feedback. While we are sorry to hear that they are not convinced by the current version of the manuscript, we disagree with their overall assessment. We hope that our responses to their concerns will persuade them that, while cumulative pressure mapping does not capture all pressures on the environment, it is a useful surrogate and tool for use in ecological research, conservation, and environmental planning. In this response, we would like to clarify the scientific rationale, the methodological robustness, and the ecological and policy relevance of this work.

Importantly, in their comments, the reviewer notes that our manuscript fails to demonstrate the practical significance of the datasets we present and share here, through analysis and discussion. Therefore, we would like to emphasize to the reviewer that Earth System Science Data is a data journal dedicated to transparent documentation and validation of datasets, rather than hypothesis-driven ecological interpretation. Our submission qualifies as a "*Data description paper*". Consistent with ESSD's scope for this type of submission, we focus on providing a reproducible, validated dataset of national pressures, leaving its ecological applications and in-depth comparison to other datasets to be explored by the broader research and policy community. Cumulative pressure mapping is a well-established methodology to approximate human pressures on the environment, and its practical significance has been tested many times, as we intend to illustrate below.

1.Rationale and novelty of the study

The rationale for this study is to produce the first nationally consistent, contemporary cumulative pressure map for terrestrial Australia since the 1980s, and a related ecological intactness index. While global human footprint and human modification datasets exist (e.g., Sanderson et al., 2002; Venter et al., 2016; Kennedy et al., 2019; Theobald et al. 2020, Theobald et al., 2025), these products are limited, to an extent, either by coarser spatial resolution or generalized global inputs. As mentioned in the revised manuscript (lines 93-100): "*may remain constrained by the need to use globally consistent datasets, which might fail to represent features such as rural roads, farm dams, and small-scale mining that are sometimes better mapped within national boundaries. National-scale assessments can overcome some of the limitations of global models by integrating detailed, locally curated datasets derived from bottom-up data collection and long-term government monitoring programs (González-Abraham et al., 2015; Hirsh-Pearson et al., 2022; Martinuzzi et al., 2021; Theobald, 2013; Woolmer et al., 2008). Such datasets are subject to national quality standards and aligned with official land-use reporting frameworks, thereby improving policy relevance (Martinuzzi et al., 2021; Scott and Rajabifard, 2017).*"

Our approach integrates 16 nationally curated, thematically detailed datasets, including the 2023 Catchment Scale Land Use Mapping (CLUM), mining cadastres, and building and infrastructure data, allowing for locally relevant representation of industrial pressures curated by authorities in each Australian jurisdiction. This scale and level of data integration have not previously been achieved for Australia and can directly support national biodiversity monitoring and reporting (e.g., the State of the Environment and Global Biodiversity Framework Targets 1–3). We have clarified this rationale more clearly in the revised Introduction and Discussion sections.

2. Methodological robustness and validation

We appreciate the reviewer's concern about the perceived "subjectivity" of the pressure scoring approach, which is a common critique of such human-pressure mapping efforts. However, the cumulative impact mapping field, although relatively recent, is grounded on well-accepted methods, and considered the best available science, even if imperfect (Halpern and Fujita, 2013). Our scoring framework is grounded in the well-established Human Footprint (HFI) methodology (Sanderson et al., 2002; Venter et al., 2016) and subsequent refinements widely used in ecological assessments and peer-reviewed studies (see Watson et al., 2023). Scores are based on empirically supported, literature-derived intensity values that capture the relative degree of land transformation associated with each pressure. The framework has been validated in numerous global and national applications (e.g., Hirsh-Pearson et al., 2022; Arias-Patiño et al., 2024).

To ensure transparency, we documented all datasets, scoring rationales, and validation procedures in detail (Sections 2.2 and 2.3). Validation against 1,397 independent high-resolution visual assessments (RMSE = 0.059, R^2 = 0.85) demonstrates strong spatial agreement between mapped and observed pressures. These results confirm that, while the scoring framework simplifies complex phenomena, the resulting cumulative pressure map is quantitatively robust and suitable for national-scale environmental analyses. Our revised manuscript now communicates this more clearly (lines 555-563), that: "*The HIF represents a cumulative model of industrial pressures rather than direct ecological conditions. High HIF values indicate areas with greater concentration or intensity of human activities, often associated with degraded states of natural systems; low values indicate areas with fewer detectable or less intense pressures, associated with intact states. As in previous studies, HIF values should be interpreted ordinally, not linearly (Watson et al., 2016; Williams et al., 2020). For example, a pixel with a value of 20 does not imply that it experiences double the pressure compared to a pixel with a value of 10; rather, it can be assumed to be experiencing a higher level of cumulative disturbance. The classified HIF map provides an intuitive framework for communication and comparison across regions, facilitating policy and planning, and has been used for many diverse conservation applications, including determining species' risk of extinction and the degree of human influence on protected areas (Allan et al., 2022; Jones et al., 2018; Di Marco et al., 2018; Torres-Romero et al., 2025).* ".

Although we acknowledge that our abstract may have led the reader to believe we claim our approach is accurate and represents all human pressures on the environment, this is not what our message was intended to convey. We do not claim that our approach is accurate in representing all human pressures, but rather that, under the assumptions we made, the agreement between our resulting HIF map and values observed through very high-resolution satellite images is very strong.

3. Ecological and practical significance

We acknowledge that the present manuscript focuses on data production and validation rather than hypothesis testing. This is because we submitted our paper as a "*Data description paper*", and we therefore consider that our submission is consistent with *Earth System Science Data*'s scope for these types of articles, where the aim is to provide reproducible, well-documented datasets for use by the broader research and policy community. Therefore, we were surprised to read that the reviewer believes these dataset

“*…lacks practical significance for both biodiversity and ecology, as the article fails to demonstrate this through analysis or discussion.”*

We would like to point out that the ecological and practical significance of cumulative pressure mapping is well established, and we would encourage the reviewer to read this literature. To make this clear, we have revised the introduction, and we include the following text: “*For example, these maps have been used to evaluate relationships between human pressures and species extinction risk (Di Marco et al., 2018; Ramírez-Delgado et al., 2022; Torres-Romero et al., 2025), analyse changes in global mammal distributions (Tucker et al., 2021), population level changes in great apes' behaviour and densities (Kühl et al., 2019; Ordaz-Németh et al., 2021), as well as model the spread of infectious diseases (Skinner et al., 2023). Moreover, cumulative pressure maps have been used in major environmental assessments, including the IPBES Global Assessment (Purvis et al., 2019), the Intergovernmental Panel on Climate Change (IPCC) reports (Masson-Delmotte et al., 2018), and the latest Global Biodiversity Outlook (Hirsch et al., 2020), where they have directly informed indicators of human impact and ecosystem condition.*”

The Human Industrial Footprint (HIF) and derived Ecological Intactness Index (EII) directly align with internationally recognised biodiversity indicators in the Kunming–Montreal Global Biodiversity Framework (CBD, 2022), supporting national and state-level monitoring of ecological integrity and restoration targets. Our text in the introduction provides an overview of how cumulative impact maps have been used; however, we would also like to share the following table with a few examples of cumulative impact mapping literature and how many times they have been cited, which we believe helps to support our claim that they have practical relevance for ecology and management. We would also encourage reading Watson et al., 2023 in Annual Reviews in Environment and Resources, which provides an in-depth review of many of the contributions human pressure mapping has made to the field of ecology, biogeography, and conservation science.

Table 1. Cumulative impact mapping assessments and number of citations of each study, highlighting the potential interest and practicality of the Australian maps for the wider community.

Reseach	Citations
Sanderson, E. W., Jaiteh, M., Levy, M. A., Redford, K. H., Wannebo, A. v, & Woolmer, G. (2002). The Human Footprint and the Last of the Wild: The human footprint is a global map of human influence on the land surface, which suggests that human beings are stewards of nature, whether we like it or not. BioScience, 52(10), 891–904. https://doi.org/10.1641/0006-3568(2002)052[0891:THFATL]2.0.CO;2	3333
Halpern, B. S., Walbridge, S., Selkoe, K. a, Kappel, C. v, Micheli, F., D'Agrosa, C., Bruno, J. F., Casey, K. S., Ebert, C., Fox, H. E., Fujita, R., Heinemann, D., Lenihan, H. S., Madin, E. M. P., Perry, M. T., Selig, E. R., Spalding, M., Steneck, R., & Watson, R. (2008). A global map of human impact on marine ecosystems. *Science (New York, N.Y.)* , *319* (5865), 948–952. https://doi.org/10.1126/science.1149345	5044
Theobald, D. M. (2013). A general model to quantify ecological integrity for landscape assessments and US application. Landscape Ecology, 28(10). https://doi.org/10.1007/s10980-013-9941-6	175
Halpern, B. S., Frazier, M., Potapenko, J., Casey, K. S., Koenig, K., Longo, C., Lowndes, J. S., Rockwood, R. C., Selig, E. R., Selkoe, K. A., & Walbridge, S. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nat Commun* , *6* , 7615. http://dx.doi.org/10.1038/ncomms8615	1317
Venter, O., Sanderson, E. W., Magrach, A., Allan, J. R., Beher, J., Jones, K. R., Possingham, H. P., Laurance, W. F., Wood, P., Fekete, B. M., Levy, M. A., & Watson, J. E. M. (2016). Global terrestrial Human Footprint maps for 1993 and 2009. Scientific Data, 3. https://doi.org/10.1038/sdata.2016.67	655
Venter, O., Sanderson, E. W., Magrach, A., Allan, J. R., Beher, J., Jones, K. R., Possingham, H. P., Laurance, W. F., Wood, P., Fekete, B. M., Levy, M. A., & Watson, J. E. M. (2016). Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. Nature Communications, 7, 12558. http://dx.doi.org/10.1038/ncomms12558	1899
Kennedy, C. M., Oakleaf, J. R., Theobald, D. M., Baruch-Mordo, S., & Kiesecker, J. (2019). Managing the middle: A shift in conservation priorities based on the global human modification gradient. Global Change Biology, 25(3), 811–826. https://doi.org/10.1111/GCB.14549	487
Beyer, H. L., Venter, O., Grantham, H. S., & Watson, J. E. M. (2020). Substantial losses in ecoregion intactness highlight urgency of globally coordinated action. *Conservation Letters* , *13* (2), e12692. https://doi.org/10.1111/CONL.12692	72
Grantham, H. S., Duncan, A., Evans, T. D., Jones, K. R., Beyer, H. L., Schuster, R., Walston, J., Ray, J. C., Robinson, J. G., Callow, M., Clements, T., Costa, H. M., DeGemmis, A., Elsen, P. R., Ervin, J., Franco, P., Goldman, E., Goetz, S., Hansen, A., … Watson, J. E. M. (2020). Anthropogenic modification of forests means only 40% of remaining forests have high ecosystem integrity. *Nature Communications 2020 11:1* , *11* (1), 1–10. https://doi.org/10.1038/s41467-020-19493-3	373
Venter, O., Sanderson, E. W., Magrach, A., Allan, J. R., Beher, J., Jones, K. R., Possingham, H. P., Laurance, W. F., Wood, P., Fekete, B. M., Levy, M. A., & Watson, J. E. M. (2016). Global terrestrial Human Footprint maps for 1993 and 2009. Scientific Data, 3. https://doi.org/10.1038/sdata.2016.67	149
Williams, B. A., Venter, O., Allan, J. R., Atkinson, S. C., Rehbein, J. A., Ward, M., di Marco, M., Grantham, H. S., Ervin, J., Goetz, S. J., Hansen, A. J., Jantz, P., Pillay, R., Rodríguez-Buriticá, S., Supples, C., Virnig, A. L. S., & Watson, J. E. M. (2020). Change in Terrestrial Human Footprint Drives Continued Loss of Intact Ecosystems. *One Earth* , *3* (3), 371–382. https://doi.org/https://doi.org/10.1016/j.oneear.2020.08.009	248
Hirsh-Pearson, K., Johnson, C. J., Schuster, R., Wheate, R. D., & Venter, O. (2022). Canada's human footprint reveals large intact areas juxtaposed against areas under immense anthropogenic pressure. Facets, 7, 398–419. https://doi.org/10.1139/FACETS-2021-0063/SUPPL_FILE/FACETS-2021-0063_SUPPLEMENT4.PDF	57
Mu, H., Li, X., Wen, Y., Huang, J., Du, P., Su, W., Miao, S., & Geng, M. (2022). A global record of annual terrestrial Human Footprint dataset from 2000 to 2018. *Scientific Data* , *9* (1). https://doi.org/10.1038/s41597-022-01284-8	394

Introduction

What are the drawbacks of the existing global-scale data? What academic contributions can be achieved by addressing these drawbacks, such as improving biodiversity prediction?

> We acknowledge the significant value of global-scale maps, which enable broad-scale comparisons of human pressures and their relationships with biodiversity across the planet. However, these datasets often rely on globally consistent inputs that can overlook important local or nation-specific pressures. By contrast, national-scale assessments can leverage detailed datasets that are regularly updated, quality-controlled, and aligned with government reporting and policy frameworks. For example, pressures such as farm dams, unpaved roads, or small-scale mining are poorly represented or absent from global products but are arguably better represented using national datasets. We have clarified this idea in the introduction section, lines 89-100:
>
> *"Global efforts have mapped pressures across Australia, but some of these use a limited set of globally available datasets to represent pressures (Gassert et al., 2023; Mu et al., 2022; Sanderson et al., 2002; Williams et al., 2020) and therefore miss nation-specific critical pressures (Hirsh-Pearson et al., 2022). Others, such as Theobald et al. (2020, 2025), incorporate additional pressures and finer spatial resolution, which likely improves their representation of human influence across many landscapes (Arias-Patino et al., 2024). However, these models may remain constrained by the need to use globally consistent datasets, which might fail to represent features such as rural roads, farm dams, and small-scale mining that are sometimes better mapped within national boundaries. National-scale assessments can overcome some of the limitations of global models by integrating detailed, locally curated datasets derived from bottom-up data collection and long-term government monitoring programs (González-Abraham et al., 2015; Hirsh-Pearson et al., 2022; Martinuzzi et al., 2021; Theobald, 2013; Woolmer et al., 2008). Such datasets are subject to national quality standards and aligned with official land-use reporting frameworks, thereby improving policy relevance (Martinuzzi et al., 2021; Scott and Rajabifard, 2017)."*

How do you define 'pressure'? What is the relationship between different pressures and biodiversity? The authors should reconsider the correlation between the Human Impact Factor (HIF) and biodiversity.

> We thank the reviewer for raising this important conceptual point. We now explicitly provide a definition for the term pressure for our study, and state that it follows the IUCN threat classification system (Salafsky et al., 2008, 2025) and is equivalent to "stressor" or "threat" within that taxonomy. The text (lines 47-49) included in the introduction reads as follows:
>
> "*Here, we use the term "pressure" to denote human activities with the potential to harm nature (Borja et al., 2006; Martins et al., 2012), broadly corresponding to "direct threats" or "stressors" in the IUCN Threat and Stress Classification Scheme (Salafsky et al., 2008, 2025).*"
>
> The Human Industrial Footprint (HIF) quantifies the spatial distribution and cumulative intensity of such pressures. It does not directly measure biodiversity, but it provides a well-established proxy for potential ecological impact and habitat modification. Numerous studies have shown strong correlations between cumulative pressure indices (e.g., the Human Footprint) and biodiversity outcomes, including species extinction risk (Di Marco et al., 2018; Torres-Romero et al., 2025), habitat loss (Jones et al., 2018), and ecosystem integrity (Beyer et al., 2020). We made this clear in the introduction by including the following text (lines 62-64):

"Cumulative pressure maps are understood to represent potential human influence rather than the realised ecological state or condition of natural systems (Theobald et al., 2025; Venter et al., 2016b). Nonetheless, they have become foundational datasets for ecological research, conservation planning, and environmental reporting, where higher pressures correspond to degraded or lower ecological integrity areas, and lower pressures to areas closer to their natural state. For example, these maps have been used to evaluate relationships between human pressures and species extinction risk (Di Marco et al., 2018; Ramírez-Delgado et al., 2022; Torres-Romero et al., 2025), analyse changes in global mammal distributions (Tucker et al., 2021), population level changes in great apes' behaviour and densities (Kühl et al., 2019; Ordaz-Németh et al., 2021), as well as model the spread of infectious diseases (Skinner et al., 2023). Moreover, cumulative pressure maps have been used in major environmental assessments, including the IPBES Global Assessment (Purvis et al., 2019), the Intergovernmental Panel on Climate Change (IPCC) reports (Masson-Delmotte et al., 2018), and the latest Global Biodiversity Outlook (Hirsch et al., 2020), where they have directly informed indicators of human impact and ecosystem condition."

The industrial footprint may be misleading, as I would expect to see some analysis on the trade-induced impacts of industrial sectors on biodiversity, commonly referred to as the 'footprint.'

We acknowledge that the term "footprint" can refer to multiple concepts depending on the disciplinary context. Here, however, we use it in a spatial-ecological sense, following the Human Footprint framework of Sanderson et al. (2002), to represent the spatial distribution and intensity of industrial land uses and infrastructure across Australia. We believe this meaning is clearly contextualised throughout the manuscript.

Methods

1.Do you believe your data layers can represent all pressures on biodiversity or ecology? Additionally, since the intensity of human activity can be represented by many proxies, why do you only consider population density while neglecting others, such as nighttime light?

We certainly do not believe our data layers can represent all human pressures on biodiversity or ecology, which was addressed in the limitations and uncertainty section of our first manuscript. Lines 423-426 in our first submission read:

"As with other cumulative pressure maps, some general limitations include omitting pressures such as invasive species, disease, pollution, climate change, changes in groundwater regimes, and changes in natural fire regimes. This omission is because we restricted our analysis to observable (or mapped) industrial pressures, and we note that the maps we produce do not include all disturbance regimes (and some places mapped as highly intact could be severely affected by an unmapped degrading process)."

As we have modified our introduction, this idea is now conveyed by the following text (lines 572-578):

"Our analysis does not account for all pressures, either because we lacked suitable data to represent them, or because we focused on those that are observable and related to access by humans. Excluded pressures include individual oil and gas wells, invasive species, disease, pollution, climate change, changes in groundwater regimes, and fire-regime shifts. Consequently, some areas mapped as intact could be severely affected by unmapped disturbances."

Our approach follows the established Human Footprint methodology (Sanderson et al., 2002; Venter et al., 2016) and its subsequent refinements, which emphasize representing the most relevant and consistently mapped pressures rather than all possible human activities. We therefore focused on datasets that directly capture key industrial and accessibility pressures in Australia, and datasets readily available.

Regarding human activities, we agree that they can be represented by many proxies, not only population density. Indeed, in our research, human activities are captured by all the different pressures we have included, and higher values in the resulting cumulative map, indicate higher intensity. This is now clarified in the manuscript (lines 555-560):

"*The HIF represents a cumulative model of industrial pressures rather than ecological conditions. High HIF values indicate areas with greater concentration or intensity of human activities, often associated with degraded states of natural systems; low values indicate areas with fewer detectable or less intense pressures, associated with intact states. As in previous studies, HIF values should be interpreted ordinally, not linearly (Watson et al., 2016; Williams et al., 2020). For example, a value of 20 does not imply double the pressure of 10, but rather a higher level of cumulative disturbance.* "

Nighttime lights, as mentioned in our response to another reviewer, have been used in global cumulative pressure and human modification maps (e.g., Kennedy et al., 2019; Theobald et al., 2020, 2025) as proxies for human activity where direct infrastructure data were unavailable. In our case, equivalent or higher-quality datasets were available for the same or related pressures (e.g., built environments, mining sites, pipelines, and transmission lines). For this reason, we did not include nighttime lights, as doing so would have introduced redundancy without improving spatial accuracy. This is now clearly explained in lines (187-190):

"*A notable modification from previous applications of the HIF methodology is the exclusion of nightlight data as a proxy for infrastructure in rural areas or working landscapes like mine sites (Venter et al., 2016b). We opted not to use nightlights because equivalent or higher-quality national datasets already map these features directly (e.g., CLUM 2023, Geoscience Australia's pipelines and building footprint layers).*"

2.The temporal inconsistency of data layers may introduce significant bias.

We agree with the reviewer that temporal inconsistency across data layers may contribute to the "imperfect" (but useful) representation of pressures in the map presented here. Temporal inconsistencies are indeed inherent in cumulative-pressure mapping, particularly when integrating datasets compiled under different monitoring cycles. We addressed this by (1) prioritizing the most recent and nationally consistent datasets available, with most layers representing conditions between 2018 and 2023; (2) selecting data versions that are temporally aligned where possible to minimize discrepancies; (3) noting that any residual differences are likely to have a minor influence on broad spatial patterns of cumulative pressure, given the dominance of persistent infrastructure and land-use types; and (4) explicitly defining the Human Industrial Footprint as a contemporary snapshot of cumulative industrial pressures rather than a time-series analysis. We have now clarified this rationale in the *Methods* section (lines 191–194): "*Although some of the input datasets differ slightly in their reference years, most represent conditions between 2018 and 2023 and together provide an up-to-date national view of cumulative industrial pressures. These small temporal differences reflect the different update cycles of national and state agencies, but because* *most pressures (such as infrastructure, land use, and mining) are long-lasting features, they are unlikely to meaningfully affect the overall spatial patterns of pressure across Australia*."

Moreover, Table 1 shows the currency date for each dataset, showing a median year of 2018, which will allow the users to better interpret the resulting maps.

3. How do you determine the score and spatial scale for all the indirect impacts?

We thank the reviewer for this question. The scores and spatial scales for all pressures, including indirect impacts, were determined following established conventions from previous Human Footprint and cumulative pressure studies (e.g., Sanderson et al., 2002; Venter et al., 2016), and are fully detailed and justified in the Methods section and Supplementary Material. For each pressure, we defined distance-decay functions or influence zones based on empirical evidence and consistency with prior applications. In this way, indirect impacts were treated using transparent, literature-based assumptions rather than arbitrary thresholds.

4. Why do you assign the pressure of a dam to the focal pixel rather than its downstream effects?

The reviewer makes an excellent point with this comment, given dams are associated with numerous downstream effects. However, quantifying this would require complex process-based hydrological modeling, which is beyond the scope of this cumulative pressure framework. Therefore, we decided to map only the direct footprint of dams and reservoirs, consistent with other cumulative pressure maps (Theobald et al, 2022,Theobald et al, 2025, Theobald et al, 2013, Hirsh-Pearson et al, 2020, Arias-Patino et al. 2025). We now make a note about this in the methods section 2.2.8. which now reads: "*While dams also exert pressures downstream, we do not consider them in this analysis, as data for Australia is unavailable.*"

5. What does 'HFI' in line 272 refer to? It appears to be an abbreviation error.

We have corrected it to "HIF"

6.The single score for cropland seems insufficient to represent the pressure on biodiversity, as there are distinct differences under various intensification levels, land-use strategies, and biochemical conditions.

We thank the reviewer for this thoughtful comment. We agree that cropland intensity can vary markedly depending on management practices, land-use strategies, and biochemical conditions. However, for this national-scale analysis, we applied a single score for croplands to maintain methodological consistency and comparability across all pressure layers. As with other pressure categories (e.g., intensive land uses, transport infrastructure), each was scored uniformly following the Human Footprint framework (Venter et al., 2016; Arias-Patiño et al., 2024), which emphasizes relative, not absolute pressure intensities.

Our approach, therefore, focuses on representing the spatial extent of major land-use pressures rather than their internal gradients, ensuring transparency and reproducibility across datasets. We have nonetheless acknowledged in the revised Method2.2.5 (lines 237-239), that:

"We acknowledge that different crops might exert different pressure intensity on the environment, and while our study maintains consistency with what has been done in previous HIF studies, future work could explore modifying cropland pressures based on intensification levels and biochemical conditions."

Results

1. What is the ecological significance of the HIF value? I suspect that pixels with the same cumulative HIF value may experience different levels of pressure on ecology or biodiversity. Additionally, can I assert that a pixel with an HIF value of 40.0 experiences double the pressure of a pixel with an HIF value of 20.0?

Indeed, the reviewer is right in noting that the same cumulative HIF value may have different impacts through out the landscape. This is a limitation in cumulative impact maps, and it has been clearly stated in the limitations sections (lines 578-581):

"*Consequently, some areas mapped as intact could be severely affected by unmapped disturbances. Similarly, the ecological response to equivalent pressures likely varies among ecosystems, meaning HIF values indicate potential rather than realized impacts. This being said, the HIF has been shown to be an excellent proxy for assessing species extinction and ecological degradation (see discussion in Watson et al. 2023b).*"

We have now clarified in the Discussion section, that the Human Industrial Footprint (HIF) is an ordinal indicator of cumulative industrial pressures, not a linear measure of ecological impact. An HIF value of 40 does not represent double the pressure of 20. The ecological significance of Human Footprint values has been extensively assessed and validated in previous studies (e.g., Sanderson et al., 2002; Venter et al., 2016; Williams et al., 2020), as reviewed in the revised Introduction and Discussion. Example text from the discussion Lines 555-560: *"The HIF represents a cumulative model of industrial pressures rather than ecological conditions. High HIF values indicate areas with greater concentration or intensity of human activities, often associated with degraded states of natural systems; low values indicate areas with fewer detectable or less intense pressures, associated with intact states. As in previous studies, HIF values should be interpreted ordinally, not linearly (Watson et al., 2016; Williams et al., 2020). For example, a value of 20 does not imply double the pressure of 10, but rather a higher level of cumulative disturbance*."

2. There is a numerical inconsistency regarding the R^2 value in line 333 and figure 2. Why did you use R^2, which typically measures goodness of fit, instead of Pearson's r?

We thank the reviewer for noting this inconsistency. We have corrected the small discrepancy between the R^2 value in line 333 and Figure 2. We used the coefficient of determination (R^2) rather than Pearson's r because our objective was to evaluate the proportion of variance in validation scores explained by the modeled cumulative pressures, consistent with prior human footprint validation studies (e.g., Venter et al., 2016; Hirsh-Pearson et al., 2022).

3. I noticed a higher bias in regions with a high footprint. Why is that?

We appreciate the reviewer's attention to detail in the results section. The slightly higher bias in regions with a high footprint likely reflects the combined effect of (i) the greater spatial heterogeneity of pressures in densely modified landscapes, and (ii) the cumulative nature of the index, where multiple overlapping pressures can amplify small positional or classification inaccuracies in the source layers. In such areas, small spatial misalignments or local overestimations of one pressure (e.g., roads or intensive land uses) can disproportionately affect the cumulative score. As noted by Arias-Patiño et al. (2025), uncertainty tends to be higher in areas where multiple pressures overlap. However, our simulations show that even when pressure scores were varied by ±50%, nearly 90% of the validation plots showed very low deviations (±0.02), confirming that overall model performance remains robust despite localized uncertainty in high-footprint areas. We now have a sentence stating this in section 3.2 (lines 494-496), which now reads:

"Higher uncertainties in areas with HIF likely reflect the accumulation of positional and classification errors from overlapping layers and the fine-grained heterogeneity typical of developed landscapes."

4.The validation was based on subjective scoring, which is insufficient to support the reliability of the data.

Our validation follows established remote-sensing and spatial-modeling practices, where visual interpretation of high-resolution imagery is used to assess map accuracy (e.g., Venter et al., 2016). This approach is standard for evaluating cumulative pressure maps (Arias-Patino et al., 2024; Hirsh-Pearson et al., 2022; Kennedy et al., 2019; Martinuzzi et al., 2021; Venter et al., 2016a, b; Williams et al., 2020), as it allows for systematic, repeatable comparison between observed human modification and mapped results. Therefore, while expert interpretation is part of the process, it is applied consistently and transparently, in line with widely accepted map-validation protocols.

5.How can you claim that your production is more accurate solely based on low correlation with existing global-scale data? Furthermore, how do you define the accuracy of your work?

We appreciate the reviewer's comment and agree that our earlier wording could have been interpreted as claiming higher accuracy. We have revised the text accordingly to avoid this implication. Our intention was not to assert that the Australian Human Industrial Footprint (HIF) is more accurate than existing global products, but rather to illustrate how the use of nationally curated, higher-resolution datasets enhances spatial representation of pressures within Australia. We have clarified that "accuracy" in this context refers to the degree of correspondence between mapped pressures and observed human disturbances in high-resolution imagery. To better illustrate this, we replaced the RMSE comparison with a visual spatial comparison (new Figure 6), which shows where the national HIF diverges from global Human Footprint datasets (Williams et al., 2020; Gassert et al., 2023). This figure highlights improvements in the representation of details of nationally relevant pressures, such as native pasturelands, unpaved roads, and farm dams, without making claims of overall higher accuracy. Sections 2.2.3 and 3.3 have been revised to reflect this clarification.

Subsection 2.2.3 in the revised methods now reads as follows:

"*To assess the added value of the fine-scale national Human Industrial Footprint (HIF), we carried out a visual comparison with global Human Footprint datasets available at 1 km for 2013 (Williams et al., 2020) and at 100 m resolution for 2020 (Gassert et al., 2023). These comparisons were used to qualitatively evaluate how well the HIF captures the spatial* *patterns of cumulative pressures relative to global assessments. Because the datasets differ in resolution, input data, set of mapped pressures, and some assumptions, interpreting a direct quantitative comparison would be limited."*

Subsection 3.3 now reads:

"A visual comparison between the national HIF and the global Human Footprint maps at 1 km and 100 m resolutions reveals broadly similar patterns of cumulative pressures across the continent. However, clear mismatches are evident even at a coarse scale. For instance, large parts of inland Australia appear pressure-free in the global maps, yet these areas coincide with native pasturelands captured in the Australian analysis (Fig. 6a). At finer scales, differences become more apparent, arising both from the coarser resolution of the 1 km dataset and from the inclusion of additional nationally curated pressures in the HIF. Examples include Kangaroo Island (Fig. 6b) and the city of Townsville and its surroundings (Fig. 6c), where the national HIF captures unpaved roads, forestry, and pasturelands that are absent in the global products. The Australian HIF also shows finer detail in cumulative pressures within urban centres and peri-urban areas, where features such as farm dams, reservoirs, and unpaved roads are more accurately represented."

6. What is the purpose of calculating the Ecological Impact Index (EII)? It does not seem to indicate any practical significance of your findings.

We agree that our initial submission did not clearly articulate the purpose of calculating the Ecological Intactness Index (EII), or how it differs from the Human Industrial Footprint (HIF). The EII complements the HIF by translating cumulative pressure data into an ecologically interpretable measure of structural intactness; that is, how the spatial configuration and continuity of natural areas are affected by human pressures.

Whereas the HIF represents the distribution and intensity of industrial pressures, the EII captures how these pressures affect the spatial configuration and continuity of remaining natural areas, accounting for fragmentation and habitat quality (degradation). We have made this clear now in the introduction (lines 74-86), methods (lines 421-430), and discussion (lines 564-567) sections. We have also added a new figure 7 to explain how the two maps differ, and how the EII can be used to interpret intactness. For example, lines 74-87 now reads:

"*Pressure maps have been used as surrogates for ecological intactness. However, intactness (often used as a synonym for areas of high integrity) describes the degree to which systems retain their natural composition, structure, and function (Nicholson et al., 2021). Pressure maps may therefore not fully capture intactness, as they do not account for the spatial configuration and habitat-quality context surrounding each pixel (Theobald et al., 2025). To overcome this, Beyer and colleagues (2020) developed a metric to estimate ecological intactness, which integrates relative habitat quality with the degree of fragmentation, using cumulative pressure maps as the base layer. This approach provides a spatially explicit measure of the structural dimension of integrity, complementing cumulative pressure maps that represent direct human influence. Developing intactness metric datasets is particularly important in the context of the global conservation agenda (Mendez Angarita et al., 2025) because targets have been set for retaining ecological intactness in the Kunming-Montreal Global Biodiversity Framework (GBF) (CBD, 2022), to which Australia is a signatory and has made commitments to. Specifically, the ecosystem component of the GBF's Goal A aims to ensure "the integrity, connectivity, and resilience of all ecosystems are maintained,* *enhanced, or restored, substantially increasing the area of natural ecosystems by 2050". This is to be achieved through activities including protection and restoration (Targets 1-3) (CBD, 2022)*."

Together, the HIF and EII provide a nationally consistent baseline for assessing ecosystem condition, identifying intact and degraded landscapes, and informing policy applications such as ecosystem-integrity targets under the Kunming–Montreal Global Biodiversity Framework (CBD, 2022). While this study focuses on documenting and validating the datasets, their practical significance lies in enabling future analyses of ecological conditions, restoration priorities, and monitoring trends of integrity across Australia.

Discussion

1.Please expand on the novelty, results, practical implications, and potential applications of your work.

We appreciate this comment and have refined the Introduction and Discussion sections to more clearly articulate the novelty, and the potential practical implications, and applications of the Human Industrial Footprint (HIF) and Ecological Intactness Index (EII). While *Earth System Science Data* papers follow a concise structure focused on data description and interpretation rather than extended analysis, we now emphasize that this is the first national cumulative pressure map for Australia since the National Wilderness Inventory, developed using harmonized, thematically detailed datasets at 100 m resolution. The revised text highlights how these complementary datasets provide transparent, updateable baselines to inform conservation planning, environmental reporting (e.g., *State of the Environment*), and national and global biodiversity targets. These clarifications strengthen the presentation of the datasets' novelty and their broad practical relevance while maintaining the concise ESSD format.

Reviewer 3

Based on 16 pressure layers of national relevance, the authors have developed the Human Industrial Footprint (HIF) and Ecological Intactness Index (EII) with high spatial resolution for Australia. These two indices are of critical significance for guiding vegetation restoration initiatives and biodiversity conservation practices. Overall, the manuscript is well-structured, with clear logical flow and coherent writing. To further enhance its academic rigor and contribution, the following suggestions are proposed for potential revisions:

> We thank the reviewer for their positive assessment of our work and for the constructive suggestions that follow.

1. Introduction (Lines 54–60): The current paragraph places excessive emphasis on the detailed background of the Global Biodiversity Framework (GBF). Given the focus of this study, an in-depth elaboration of the GBF is unnecessary and may divert attention from the core research context. Instead, the authors should systematically synthesize and present global advancements in pressure mapping research—a key foundation for justifying the novelty of this study. For instance, studies such as Gassert et al. (2023) and Arias-Patino et al. (2024) should be integrated to clarify research gaps that the current HIF and EII aim to address.

> We thank the reviewer for this suggestion that will help set the context for cumulative pressure mapping, and its potential applications in ecology and environmental management. We have rebalanced the Introduction accordingly. The GBF description was condensed to focus on the most relevant components (Goal A and Targets 1–3) while removing excessive policy detail. In its place, we expanded the synthesis of global cumulative pressure mapping developments (paragraphs 2–3), referencing key recent studies (Gassert et al., 2023; Arias-Patiño et al., 2024; Theobald et al., 2025) to illustrate methodological advances and research applications. This revision strengthens the global context and highlights the specific gap our national analysis addresses.
>
> Lines 46-85 in the introduction section now read: "*The field of cumulative pressure mapping, in which data on multiple pressures are integrated under a spatial model (maps), has become a widely used approach to estimate human pressures on the environment (Watson et al., 2023b). Here, we use the term "pressure" to denote human activities with the potential to harm nature (Borja et al., 2006; Martins et al., 2012), broadly corresponding to "direct threats" or "stressors" in the IUCN Threat and Stress Classification Scheme (Salafsky et al., 2008, 2025). Such pressure maps are increasingly used as proxies for human influence on ecological state and condition, particularly within pressure-state-response frameworks used to guide adaptive planning and management (Watson and Venter, 2019). The conceptual foundations of cumulative pressure maps emerged in the 1980s (Lesslie and Taylor, 1983, 1985; McCloskey and Spalding, 1989), but the discipline has expanded rapidly over the past two decades, with advances in Earth observation and geographic information systems (Watson et al., 2023b; Watson and Venter, 2019). The Human Footprint of Sanderson and colleagues (2002) is arguably one of the most influential early global assessments of humanity's influence on the terrestrial planet, and mapped at a 1 km resolution, provided a framework to quantify anthropogenic influence across nine major pressures. This framework has since been refined and adapted to incorporate additional pressures (Kennedy et al., 2019; Venter et al., 2016a), regional contexts (González-Abraham et al., 2015; Hirsh-Pearson et al., 2022; Martinuzzi et al., 2021; Theobald, 2013; Woolmer et al., 2008), and alternative models for aggregating pressures (Halpern et al., 2008; Theobald, 2013), while recent efforts have*

achieved spatial resolutions of 100–300 m and annual updates (Gassert et al., 2023; Mu et al., 2022; Theobald et al., 2025). Comparable methods have also been applied in marine systems to quantify the extent and intensity of human use of the oceans (Ban et al., 2010; Halpern et al., 2008, 2015; Micheli et al., 2013).

Cumulative pressure maps are understood to represent potential human influence rather than the realised ecological state or condition of natural systems (Theobald et al., 2025; Venter et al., 2016b). Nonetheless, they have become foundational datasets for ecological research, conservation planning, and environmental reporting, where higher pressures correspond to degraded or lower ecological integrity areas, and lower pressures to areas closer to their natural state. For example, these maps have been used to evaluate relationships between human pressures and species extinction risk (Di Marco et al., 2018; Ramírez-Delgado et al., 2022; Torres-Romero et al., 2025), analyse changes in global mammal distributions (Tucker et al., 2021), population level changes in great apes' behaviour and densities (Kühl et al., 2019; Ordaz-Németh et al., 2021), as well as model the spread of infectious diseases (Skinner et al., 2023). Moreover, cumulative pressure maps have been used in major environmental assessments, including the IPBES Global Assessment (Purvis et al., 2019), the Intergovernmental Panel on Climate Change (IPCC) reports (Masson-Delmotte et al., 2018), and the latest Global Biodiversity Outlook (Hirsch et al., 2020), where they have directly informed indicators of human impact and ecosystem condition."

Pressure maps have been used as surrogates for ecological intactness. However, intactness (often used as a synonym for areas of high integrity) describes the degree to which systems retain their natural composition, structure, and function (Nicholson et al., 2021). Pressure maps may therefore not fully capture intactness, as they do not account for the spatial configuration and habitat-quality context surrounding each pixel (Theobald et al., 2025). To overcome this, Beyer and colleagues (2020) developed a metric to estimate ecological intactness, which integrates relative habitat quality with the degree of fragmentation, using cumulative pressure maps as the base layer. This approach provides a spatially explicit measure of the structural dimension of integrity, complementing cumulative pressure maps that represent direct human influence. Developing intactness metric datasets is particularly important in the context of the global conservation agenda (Mendez Angarita et al., 2025) because targets have been set for retaining ecological intactness in the Kunming-Montreal Global Biodiversity Framework (GBF) (CBD, 2022), to which Australia is a signatory and has made commitments to. Specifically, the ecosystem component of the GBF's Goal A aims to ensure "the integrity, connectivity, and resilience of all ecosystems are maintained, enhanced, or restored, substantially increasing the area of natural ecosystems by 2050". This is to be achieved through activities including protection and restoration (Targets 1-3) (CBD, 2022)."

2. Methods: While the Discussion section addresses uncertainties associated with data sources and methodological design, an important uncertainty remains unaccounted for: the influence of fire regimes. As a dominant disturbance in Australian ecosystems, fire exerts profound effects on both vegetation dynamics and intensive land use. For example, forestry operations across different regions exhibit varying levels of fire resistance, which may lead to divergent HIF/EII values even for the same

ecosystem. The authors are advised to discuss whether fire regime variables were incorporated into the index development framework; if not, an additional analysis of fire-induced uncertainty should be added to strengthen the robustness of the methods.

We thank the reviewer for highlighting the importance of fire regimes in shaping Australian ecosystems and agree that fire represents a major ecological driver. As noted in the revised Methods (Section 2.2), we did not include fire in this analysis because suitable national spatial data were unavailable and distinguishing natural from human-induced fires remains challenging, particularly at the continental scale (Bowman et al., 2020; Andela et al., 2019; Theobald et al., 2025). Existing national and global fire datasets typically record burned area or frequency but lack consistent attribution of ignition source or management intent, making them difficult to integrate within a framework focused on direct industrial human pressures (but see Kelley et al 2025 for advances in Fire mapping).

In the revised text, we now clearly acknowledge these limitations and clarify that the framework remains flexible for incorporating new pressures (such as changed fire regimes) once appropriate datasets become available. The updated paragraph in Methods 2.2 reads as follows(lines 121-125): "*Climate change and changed fire regimes present additional challenges in distinguishing natural from human-induced events (Bowman et al., 2020; Theobald et al., 2025). Nevertheless, we acknowledge that changes in fire regimes increasingly threaten Australian biodiversity (Doherty et al., 2024; Ward et al., 2020). The framework we use remains flexible, allowing future integration of new pressures (such as changed fire regimes) as suitable datasets become available.*"

3.Section 3.3 (Lines 365–370): The comparison between the proposed HIF/EII and existing Global Human Footprint datasets is currently insufficiently detailed. To fully demonstrate the advantages and limitations of the new indices, the authors should expand this section to include spatial comparative analyses by visualizing spatial patterns of discrepancies (e.g., via difference maps) to identify regions where the new indices diverge most significantly from global datasets.

We thank the reviewer for this constructive suggestion. We have substantially revised Section 3.3 to include new comparative figures (Figure 6) that illustrate spatial discrepancies between the national Human Industrial Footprint (HIF) and existing global Human Footprint datasets (Williams et al., 2020; Gassert et al., 2023). These additions better illustrate the advantages of the national product in capturing fine-scale, nationally relevant pressures. However, while we believe this illustration is important for readers to assess the level of detail that can be achieved through national cumulative pressure maps, a thorough comparison with global maps was not our aim.

The revised subsection 3.3 reads as follows: *"A visual comparison between the national HIF and the global Human Footprint maps at 1 km and 100 m resolutions reveals broadly similar patterns of cumulative pressures across the continent. However, clear mismatches are evident even at a coarse scale. For instance, large parts of inland Australia appear pressure-free in the global maps, yet these areas coincide with native pasturelands captured in the Australian analysis (Fig. 6a). At finer scales, differences become more apparent, arising both from the coarser resolution of the 1 km dataset and from the inclusion of additional nationally curated pressures in the HIF. Examples include Kangaroo Island (Fig. 6b) and the city of Townsville and its surroundings (Fig. 6c), where the national HIF captures unpaved* *roads, forestry, and pasturelands that are absent in the global products. The Australian HIF also shows finer detail in cumulative pressures within urban centres and peri-urban areas, where features such as farm dams, reservoirs, and unpaved roads are more accurately represented."*

Moreover, we have also modified the figure showing the EII map, and now have included two panels illustrating how the EII, estimate changes in structural intactness where the HIF maps no pressures. Please see Figure 7 in the revised manuscript.

4. The current Discussion section functions more as a Conclusion, as it primarily summarizes key findings rather than engaging in critical, in-depth synthesis.

We agree that the *Discussion* section in ESSD papers should provide more than a summary but also note that ESSD follows a concise structure where the Discussion is typically brief and focused on dataset interpretation, use, and limitations rather than extended theoretical synthesis. Within this format, we have refined the section to more clearly articulate the conceptual distinction and complementary value of the HIF and EII, explain how the HIF should be interpreted (ordinally rather than linearly), and highlight their potential applications and limitations as spatial models. These clarifications strengthen the interpretive depth of the section while maintaining the concise and data-focused style expected for ESSD papers.

5. The Discussion section can explicitly outline targeted application scenarios for the two indices to enhance their relevance for policymakers and practitioners. For example: compare the suitability of HIF and EII for specific management objectives (e.g., Is HIF more effective for evaluating industrial disturbance risks, while EII better captures ecological integrity for biodiversity hotspots?

This point is closely related to Comment 4, and we have addressed both together. The revised *Discussion* now clarifies the complementary roles and intended applications of the Human Industrial Footprint (HIF) and the Ecological Intactness Index (EII), noting that the HIF is suited to evaluating the distribution and intensity of industrial pressures, while the EII provides an independent measure of ecological integrity. These additions strengthen the relevance of both datasets for policy, management, and reporting contexts while maintaining the concise structure expected for *ESSD* papers.

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